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VOL II

CHARACTERISTICS OF OPTICAL FIRE DETECTOR FALSE ALARM SOURCES AND QUALIFICATION TEST PROCEDURES TO PROVE IMMUNITY, PHASE II, VOL II

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This study identified possible sources of UV, IR and visible radiations that may cause an optical fire detector to false alarm and/or affect its fire detection performance. The spectral irradiances of JP-4 pan fires and a multitude of lamps, hot bodies, and other of radiation stimuli that an optical detector may be exposed to in any type of aircraft shelter, hanger, facility, or ground location, were determined. Knowing the spectral irradiances of the required fire size and distance to be detected, it was then possible to determine at what distances would the potential false alarm source have to be to equal or exceed the fire's spectral irradiances in the 185nm - 250nm and 4.41m bands. Considering the possible distance from detector to source, candidate false alarm sources were selected for detector immunity testing. Qualification test procedures were developed and tested. It was concluded that there are many possible false alarm sources and, if located too close to a detector, and the stimuli are modulated, most optical fire detectors would alarm.

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PREFACE

This final report was prepared by Donmar Limited, 901 Dover Drive, Suite 120, Newport Beach, California 92660, under Contract F08635-91-C-0129, with Wright Laboratory, Fire Protection Section (WL/FIVCF), Tyndall AFB, FL 32403-5323.

The period of performance for this contract extended from April 8, 1991, through October 8, 1992. The WL/FIVCF Project Officer was Mr. Charles W. Risinger.

The authors wish to acknowledge the cooperation and assistance provided by Civil Engineering, Fire Department, Flight Test, and other department personnel at Edwards AFB in the conduct of the field measurements. Also, the authors thank the Fire Departments at Travis AFB, Beale AFB, Norton AFB, Hickam AFB, and Bitburg AFB for their assistance during this effort. The cooperation of the fire detector industry in this effort to increase fire detector reliability is also greatly appreciated.

This technical report was submitted as part of the Small Business Innovative Research (SBIR) Phase II Program and has been published according to SBIR Directives in the format in which it was submitted.

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EXECUTIVE SUMMARY

A. OBJECTIVE

The objectives of this project were: (1) to determine the nature and properties of objects and phenomena that may cause an optical fire detector to false alarm and/or affect its ability to identify fire; and (2) to develop qualification test procedures to determine an optical fire detector's false alarm immunity.

B. BACKGROUND

It was assumed that the minimum detection threshold of a detector must be at least equal to the spectral irradiance from the specified type and size fire at its specified maximum distance from the detector. The fire type, size, and distance assumed herein for analysis was the standard Air Force specification of a 2-foot x 2-foot JP-4 panfire at a distance of 100' in 5 seconds or less (or a 1-foot x 1-foot at 50 feet). Spectral irradiance data were measured during controlled burns.

C. SCOPE

Consideration was given to both monospectral detectors (e.g. UV, IR, visible) and multispectral detectors (e.g. UV/IR and other combinations of the EM spectrum) in this study. The bands where most of these detectors operate are 185nm-250nm centered at about 220nm in the UV, and about 4.2μm-4.6μm centered at 4.4μm in the IR.

Possible false alarm sources were identified by analyzing past events, reviewing Air Force bases in the U.S. and Europe, discussing false alarm problems with detector manufacturers, and analyzing objects and phenomena that may exist in the field-of-view of a detector when used in various applications. Spectral irradiances were then determined by field measurements concentrated at Edwards AFB, laboratory measurements, and literature reviews. These spectral irradiances were then compared to the measured spectral irradiances in the same bands of the 2-foot x 2-foot JP-4 fire at 100 feet. Sources were selected that either individually or in combination had sufficient irradiances to satisfy what should be the minimum thresholds of an optical fire detector in its band(s) of operation. Manufacturers were asked to supply detectors set at the above threshold level. These were used to develop test procedures for the false alarm sources that may be found in any typical Air Force hangar, shelter, or facility. Distances between source(s) and detector were determined for practical applications.

D. CONCLUSION

It was concluded that many types of UV and/or IR sources can satisfy the minimum energy flux threshold of a fire detector commonly used in AF hangar and shelter applications. The nature

and properties of these sources were identified in great detail in this study. Moreover, although most detectors today use other features in their detection logic, such as modulation of the incoming IR signal or ratioing of two wavelengths, all these features can be and have been duplicated during routine aircraft-associated ground operations.

E. RECOMMENDATION

This study resulted in a recommendation of a set of test procedures that can be included in an RFP, a purchase description, or a specification to help assure that the detector(s) being purchased meet the reliability expectation of the government before delivery and installation.

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SECTION I

INTRODUCTION

A. FOREWORD

The objective of this compilation is to provide the designers and users of fire detection systems with a baseline of data that can provide practical and necessary spectral, temporal, spatial, and whatever other characteristics of relevant radiation sources that can possibly cause a fire detector to "false alarm". This document is an extension of the main body of the final report and may contain some duplication.

It is recognized that there can be gaps in this information, as the scope of this endeavor was limited. Every effort was made, however, to make this compilation current, thorough, and accurate.

Edwards AFB served as the guideline for assessing relevancy of the vast multiplicity of possible radiation sources, and was used as the basis for making a first cut of the material available. Recognizing, however, that the worldwide scenario could include an unknown number of other candidate radiation sources, the selection screening was broadened to include information pertaining to other AF bases.

The sources of the data are several:

(1) manufacturers' publications
(2) research reports
(3) books
(4) papers
(5) Laboratory measurements and computations
(6) on-site visits to AF bases in U.S. and Europe

The references and bibliography are given at the end.

B. SPECTRAL ENERGY DISTRIBUTION OF SOME IMPORTANT LIGHT SOURCES

As a preview summary of what is detailed in this compilation, Table 1 provides a sampling of the following important categories of relevant light sources:

1. high intensity discharge lamps

2. incandescent lamps

3. cool white fluorescent lamps

Study of this Table shows that each light source can potentially trigger optical fire detectors, depending on associated parameters such as spectral band, distance, and other features.

SECTION II

DETAILED DATA FOR RELEVANT RADIATION SOURCES

A. Natural Light Sources

This part of the compilation covers in detail in each section the relevant data for each source which is a candidate false alarm source. Of particular interest are the spectral, temporal, spatial, and whatever other features that are unique to the source that could be involved in affecting the fire decision of an optical fire detector.

Natural Light Sources	Approximate Average Luminance cd/m^2	Dominant Wavelength Color
sun (from earth's surface):		
meridian:	1.6×10^9	white
horizon:	6×10^6	white
moon (from earth's surface):		
bright spot	2.5×10^3	white
sky:		
clear:	8×10^3	blue
overcast (time of day):	2×10^3	various
lightning flash:	8×10^{10}	white

1. Sunlight

The color temperature of the sun as received at the outside of the earth's atmosphere is about 6500° K. The energy is received at an average rate of 1350 watts per square meter. About 75% of this energy is received at the earth's surface at sea level on a clear day at the equator. See Figure 1. The illuminance at the earth's surface on a sunny day can exceed 10,000 footcandles, which on a cloudy day can drop to less than 1000 footcandles. Direct or reflected sunlight has the capability to trigger fire detectors unless they are made "solar blind".

Table 1

I. Energy Output of Some High Intensity Discharge Lamps

Type of Energy	400 Watt Mercury		400 Watt Metal Halide		400 Watt High Pressure Sodium		180 Watt Low Pressure Sodium	
	%	W	%	W	%	W	%	W
Visible	14.6		20.6		25.5		29.0	
Infrared	46.4	185.6	31.9	127.6	37.2	148.8	3.7	6.66
Ultraviolet	1.9	7.6	2.7	10.8	0.2	0.800	0	0
Conduction Convection	2.7	108	31.1	124.4	22.2	88.8	49.1	88.4
Ballast	10.1		13.7		14.9		18.2	

II. Energy output of Some Incandescent Lamps

Type of Energy	100 Watt 750 Hour Life		300 Watt 1000 Hour Life		500 Watt 1000 Hour Life		400 Watt 2000 Hour	
	%	W	%	W	%	W	%	W
Visible	10.0		11.1		12.0		13.7	
Infrared (700-5000 Nm)	72.0	72.0	68.7	206.1	70.3	351.5	67.2	268.8
Conduction Convection	18.0	18.0	20.2	60.6	17.7	88.5	19.1	76.

III. Energy Output of Some Fluorescent Lamps of Cool White Color

Type of Energy	40WT12		96 Inch T 12 800 Ma		PG 17 1500 Ma		T 12 1500 Ma	
	%	W	%	W	%	W	%	W
Visible	19.0		19.4		17.5		17.5	
Infrared (est.) (beyond 5000 nm)	30.7	12.28	30.2	12.08	41.9	31.43	29.5	22.13
Ultraviolet	0.4	0.16	0.5		0.85		0.5	
Conduction Convection (est)	36.1	14.4	36.1	14.4	27.9	20.9	40.3	30.21
Ballast	13.8		13.8		12.2		12.2	
Approx. Average Bulb Wall Temp.	41°C	105.8°F	15°C	113°F	60°C	140°F	60°C	140°F

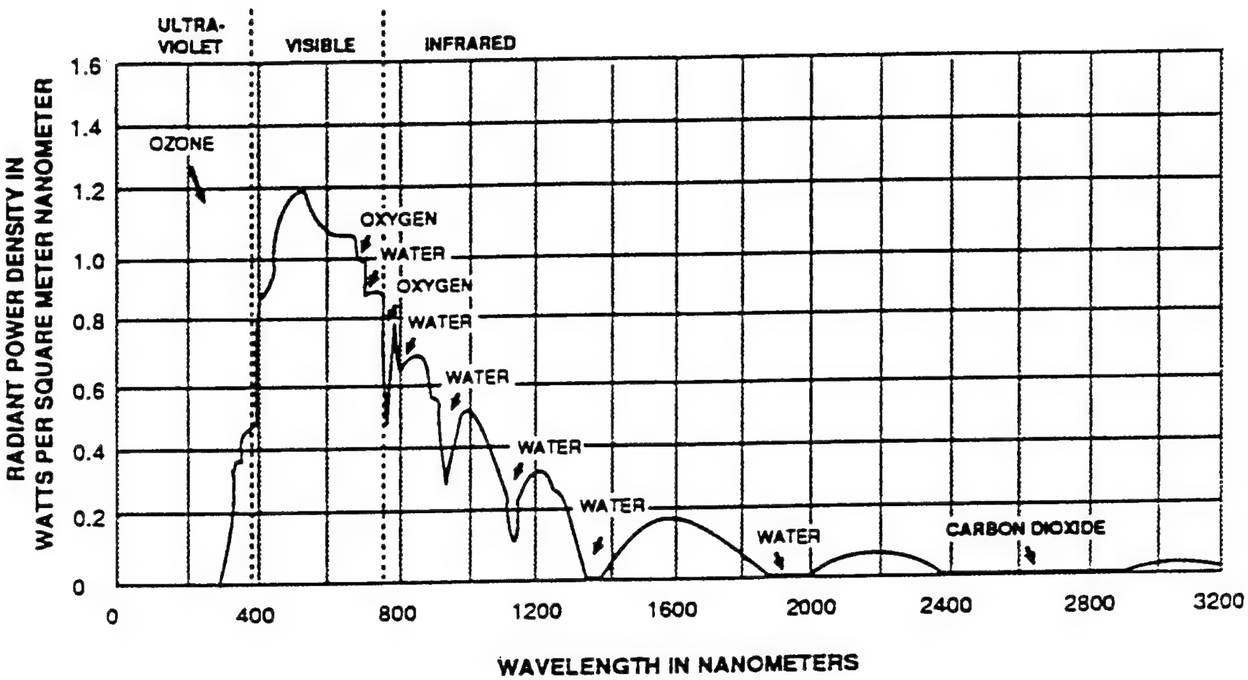


Figure 1. Spectral Distribution of Solar Radiant Power Density at Sea Level, Showing the Ozone, Oxygen, Water and Carbon Dioxide Absorption Bands.

2. Lightning

As a meteorological phenomenon arising from the accumulation of tremendous electrical charges, usually positive, in the formation of clouds, these charges are suddenly released to the ground in a spark type discharge through the atmosphere. Spectrally the discharge corresponds to that of an ordinary spark in air, which consists principally of nitrogen bands, though sometimes hydrogen lines appear, due to dissociation of water vapor. Whatever is in the atmosphere locally likewise is excited thereby into emission.

B. Combustion Sources

	Approximate Average Luminance	Dominant Wavelength Color
1) acetylene flame (Mees burner):	1.1×10^5	
2) photoflash lamps:	1.6×10^8 to 4×10^8	white
3) cigarettes, cigars, pipes:		
4) book matches, wood matches		
5) cigarette lighter		
6) kerosene heater		
7) kerosene flame (flat wick) bright spot:	1.2×10^4	
8) illuminating gas flame (fish tail burner):	4×10^3	
9) candle flame (sphere) bright spot:	1×10^4	

C. Electric Arc and Glow Lamps

1. High Intensity Discharge Lamps

		Lamp Watts	Approx. Lumens Max/Min
(1) High Pressure Sodium:		100	9,500/8,800
		400	50,000/39,000
		1000	140,000/126,000
(2) Metal Halide	(vertical):	400	40,000/31,000
	(horizontal):	400	40,000/28,000
	(vertical):	1000	125,000/11,000
	(horizontal):	1000	90,000/ --
(3) Mercury	(vertical):	400	23,125/15,300
	(vertical):	1000	63,000/43,000

a. High Pressure Sodium (HPS) Lamps

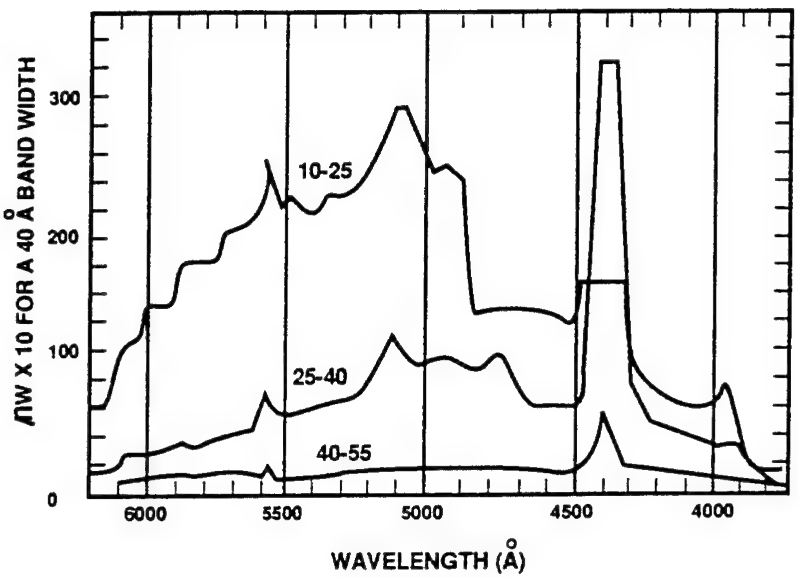


Figure 2. Spectrometer Traces: 10-25, 25-40, and 40-55 Sec After Release of Acetylene at 100 km Altitude.

Although several manufacturers make high pressure sodium lamps, a typical hangar at Edwards uses 1000 watt GTE LU1000 Lumalux HPS lamps. GE makes an equivalent LU1000 Lucalox HPS lamp. Both use an ANSI specification S52 ballast. To help understand the behavior of this combination of lamp and ballast, their operation will be described briefly.

The lamp is made with two envelopes: (1) an inner envelope of translucent polycrystalline alumina which is the arc tube containing a small quantity of sodium-mercury amalgam, and xenon as a starting gas; and (2) an outer borosilicate glass envelope which is evacuated and provides environmental protection, helps maintain the temperature, and prevents transmission of UV radiation out.

Light is produced by the electron current passing through sodium vapor in the following way. Voltage from the ballast is applied across the lamp. The "voltage" is a combination of the normal steady state voltage with a high voltage pulse superimposed. The pulse peak voltage for the 1000 watt lamp can swing from 4000 to 6000 volts. For other type HPS lamps, the pulse can swing from 2500 to 4000 volts. The pulse appears at least once per cycle for at least 1 microsecond at the peak of the steady state voltage wave.

The high voltage electric field across the xenon gas in the arc tube causes emission of electrons from the electrodes, which ionize the gas, putting it into a "glow discharge condition." The gas then breaks down fully, going into an "arc discharge condition" between the electrodes. The heat of the arc progressively vaporizes the sodium and mercury amalgam.

During the warmup period, several changes occur in the color of the light. Initially, there is a very dim bluish-white glow produced by ionized xenon in the glow discharge condition. This is followed by the typical blue of the mercury glow which is brighter, and which remains a source of UV throughout the operation of the lamp. As the brightness increases, the color changes to monochromatic yellow which is characteristic of sodium when it is at a low pressure, as it is at that time. As the pressure in the arc tube increases with the temperature, the lamp comes to full brightness with its characteristic golden white light.

The high pressure sodium lamp is the most efficient of the HID family of lamps, radiating light across the visible spectrum. Under the relatively high pressure of the lamp (200 torr), the sodium radiation of the doublet "D" lines at 589 nm is self-absorbed. Because of the relatively high pressure, the gas emits a continuum of all visible wavelengths rather than single line emissions, with a dark region at the doublet lines where self-absorption occurs. This can be seen in the figures below.

The mechanism of sustaining the arc discharge is very important. A brief consideration of Paschen's law, which applies to both the HID and fluorescent bulbs, will be helpful in understanding this aspect of sustaining the discharge. Paschen's law states that every gas breaks down into conduction at a particular voltage for a particular product value of its pressure p and its electrode spacing d. Hence, every "pd product" has its own "breakdown voltage". A study of gases shows in Figure 3 that a plot of "breakdown voltage versus the pd product" traces a "concave upward" curve, with its minimum breakdown voltage being at the bottom of the curve, and each higher breakdown voltage having two values of pd product either side of the uniquely single pd product corresponding to the "minimum breakdown voltage". As applied in the design of gas lamps, the electrode spacing is chosen to establish a particular set of breakdown voltages to fit a particular range of gas pressures. Figure 3 shows the dependence of breakdown voltage on pressure. The voltage optimum condition is when the pressure is right for the minimum breakdown voltage.

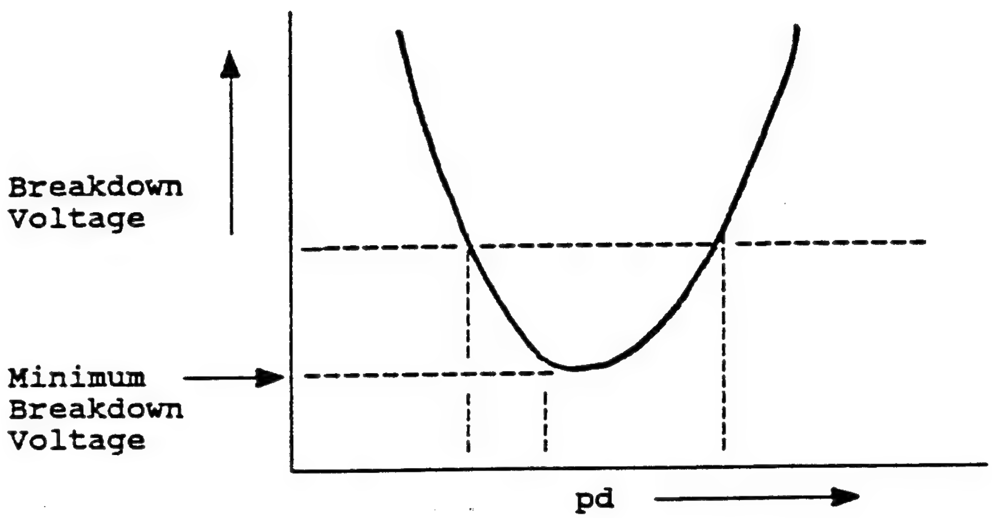


Figure 3. Paschen's Law

Understanding this law will help understand what happens during lamp warmup, and what is needed to restrike the arc when the lamp goes out, or when at end-of-life it begins to cycle on and off. The ballast is designed to automatically supply the proper voltages for these transient eventualities up to its practical limit.

For instance, during warmup, which takes 3 to 4 minutes for the HPS lamps, once every half cycle the AC voltage goes to zero, effectively bringing the discharge to a shut-off condition. But the high voltage pulse will repeat every positive half cycle with the proper voltage, if needed, to sustain the

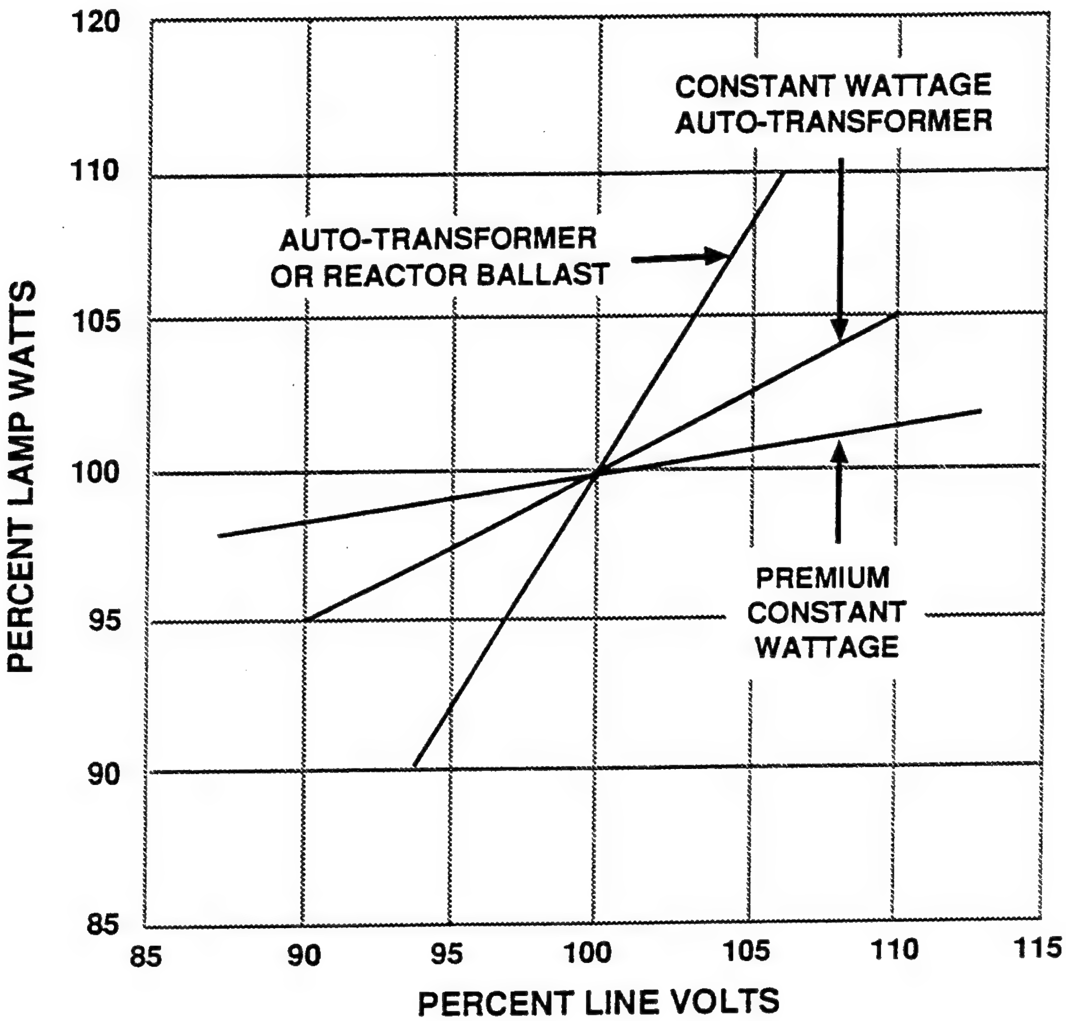


Figure 4. Effect of Line Voltage Variation on Lamp Watts with Various Ballast Types.

discharge. A line voltage drop can cause this too. Figure 4 shows how line voltage variations can impact the different ballast types, causing appreciable variations in wattage operation of the lamps to higher or lower wattages and light outputs. Once in the full steady state operating condition, all pressures and temperatures are stabilized, which takes about 10 minutes. When the HPS lamp goes off, it takes about 1 minute to restrike the arc and bring it back to full brightness.

At the end-of-life point of the lamp, the voltage demand from the ballast is highest because of pressure conditions being too high, or too low, inside the lamp. The condition of cycling on and off is the point at which the ballast is at its voltage limit for sustaining the discharge. It sustains the discharge until the pressure rises with a corresponding higher voltage demand, which the ballast is unable to provide, and the lamp goes off. On cooling slightly, the pressure now drops, enabling the lamp to restart. It continues until the increased pressure and increased voltage demand once again causes it to shut off. This cycles on and off repeatedly until the lamp is replaced, which should be done to save the ballast.

As is seen in these various transient states, it would be possible for such electrical irregularities to either produce EMI/RFI type radiation, especially with high voltage pulses, or effects in the electrical power line, that in turn may affect the fire detector or its electronics. In the arc discharge, high frequency electromagnetic radiation is being generated that can either transmit out directly, or along nearby wires, or in the power line itself. This is over and above what happens to the UV and IR irradiances produced by the lamp at those times. This needs further research.

One problem encountered in this study was the apparent lack of UV and IR spectral emission data. There is no question that very high UV and IR radiation are produced in the arc tube part of all the HID lamps sufficient to trigger the fire detectors at any practical distance. However, the outer second enclosing borosilicate glass bulb used in HID lamps also serves to cut off the UV in particular, and the IR to a certain extent. But the cutoff is not as complete as is expected.

Borosilicate or "hard" glass, used for its high temperature suitability for HID lamps, depending on its thickness, can transmit relatively high percentages of UV in the "near UV" region below 380 nm. Since a continuum of radiation is produced in the arc tube because of the high pressure condition, in combination with the intense UV line of mercury vapor at 254 nm, a relatively high percentage of UV is emitted from the arc tube to the borosilicate outer bulb. The transmittance of the outer bulb below 380 nm does not begin to reach low values until around 300 nm. What is needed is to establish how much "deep UV" gets through,

especially whenever transient events or irregularities occur as described above.

1. High Pressure Sodium Spectral Output

To exemplify how two lamps that can serve the same application, but are made by two different manufacturers, can have spectral curves that are different, are shown in Figures 5(a) and (b). Figure 5(a) is that of the GTE Sylvania 400 watt Lumalux HPS lamp, whereas Figure 5(b) is of the GE 400 watt Lucalox HPS lamp.

The spectral distribution of the energy output of these particular 400 watt lamps is given in Table 2.

Table 2

Spectral Distribution of 400 Watt HPS Energy Output

Visible Light	25.5%
Infrared	37.2
Ultraviolet	0.2
Conduction-Convection	22.2
Ballast	14.9

When 0.2% of 400 watts give an estimated total UV lamp output of $8.0 \times 10^5 \mu W$, the UV radiant intensity is estimated to be 6.37×10^4 $\mu W/ster$. At a 1 foot distance the UV radiance is estimated to be $68.5 \mu W/cm^2$.

Applying the same procedure to the 1000 watt HPS lamp, the total UV output is estimated to be $2.0 \times 10^6 \mu W$, the radiant intensity $1.59 \times 10^5 \mu W/ster$ and the UV irradiance at 1 foot is $171 \mu W/cm^2$.

How this irradiance is distributed in the several UV bands was determined in laboratory measurements. Considering that the percentage of total UV radiance of the mercury vapor and metal halide lamps is about 10 times that of the HPS lamps, they could be more likely "false alarm" sources than the high pressure sodium family of lamps.

The same determinations will be made for the IR bands of interest.

b. High Pressure Multivapor Metal Halide (MH) Lamps

The metal halide lamp is the most efficient source of white light available today. It has a quartz arc tube which is slightly smaller than that of the same wattage mercury lamp. The arc tube contains argon gas and mercury, plus thorium

iodide, sodium iodide and scandium iodide. These three materials are responsible for the outstanding performance of this remarkable light source. Manufacturers use other additives as well.

Typical combinations of halides used in metal iodide lamps are: (1) sodium, thallium and indium iodides, (2) sodium and scandium iodides, and (3) dysprosium and thallium iodides. The spectral power distributions of some of them are shown in Figure 6. Some halides, such as sodium (589 nm), thallium (535 nm), and indium (435 nm) principally produce line spectra, while others such as those of scandium, thorium, dysprosium and other rare earths produce multiline spectra across the full visible region. Other halides, such as those of tin, produce continuous spectra across the visible region. During the warmup period, the varying vaporization of these produces varying colors, and hence the designation "multivapor" lamps.

Once the arc is established, the lamp begins to warm up. As the warmup progresses, the metal additives begin to enter the arc stream and to emit their characteristic radiation. Because of the additives the sustaining characteristics of the ballast are more stringent than those required for a mercury lamp.

When the lamp is fully warmed, and the additive metals are in proper concentration in the arc, the spectral output of the lamp contains all the wavelengths to which the eye responds, giving the lamp on overall white appearance.

The spectral energy distribution of the multivapor metal halide family of lamps is the most important of the HID lamps for ultraviolet radiance. This is seen in Table 3.

Table 3

Spectral Distribution of 400 Watt MH Energy Output

Visible Light	20.6%
Infrared	31.9
Ultraviolet	2.7
Conduction-Convection	31.1
Ballast	13.7

As was stated above, Edwards AFB hangars also use two different types of metal halide lamps, and the lightall units use a third:

1. GE MVT 400/I/U SAF-T-GARD Metal Halide lamp, 400 watts, with an ANSI specification M59 ballast, used in hangars;

2. GE MVR 1500/HBU/E Metal Halide lamp, 1500 watts, with an ANSI specification M48 ballast, used in hangars;

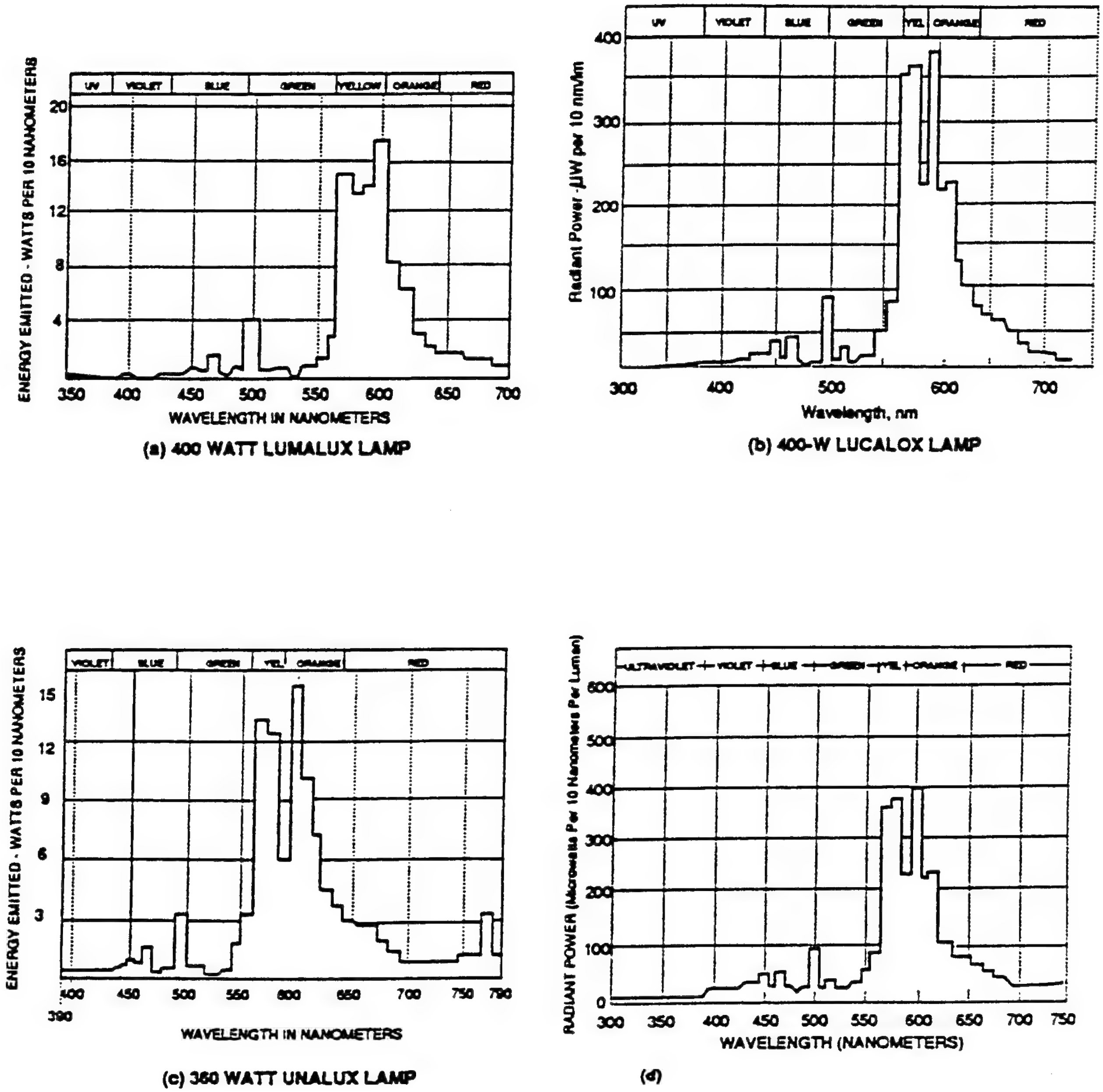
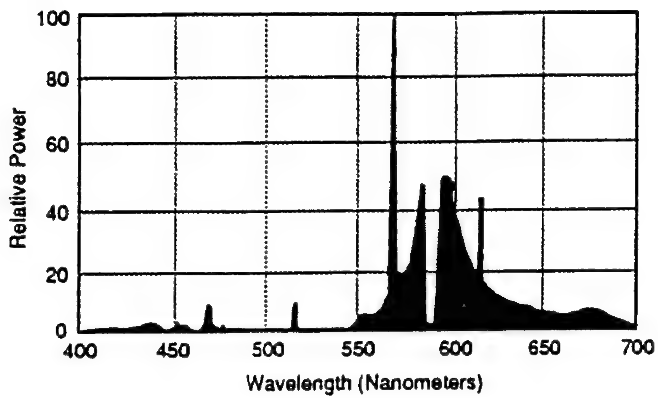
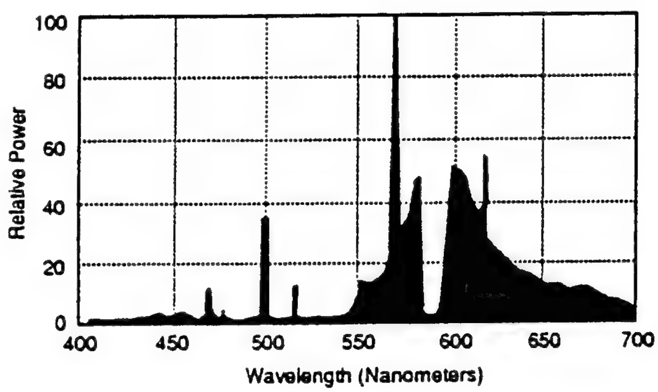


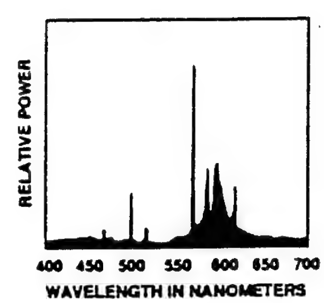
Figure 5A. Spectral Energy Distribution of High Pressure Sodium Lamps



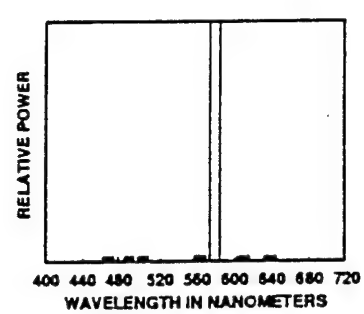
(e) CERMALUX LAMPS



(f) CERMALUX-4 LAMPS



(g) HIGH PRESSURE SODIUM LAMPS



(h) LOW PRESSURE SODIUM LAMPS

Figure 5B. Spectral Energy Distribution of High Pressure Sodium Lamps

3. GE MVR 1000/U Metal Halide lamp, 1000 watts, with an ANSI specification M47 ballast, used in 4-lamp lightall unit.

The spectra of three metal halide lamps made by the same manufacturer with different power outputs are shown in Figures 7 (a), (b), and (c). Particularly noteworthy are the UV continuum and features below 400 nm, and the similarity of the entire spectrum for 400, 1000 and 1500 watt MH lamps in Figures 7(a), (b), and (c) respectively.

Estimating the ultraviolet radiance from the 400, 1000 and 1500 watt lamps, the values are determined to be as follows:

Table 4

Radiance, Radiant Intensity and Irradiance of 3 MH Lamp Powers

Parameter	400 watt MH Lamp	1000 watt MH Lamp	1500 watt MH Lamp
Total UV Radiance	10.80 W	27.00 W	40.50 W
UV Radiant Intensity	0.859 W/ster	2.149 W/ster	3.223 W/ster
UV Irradiance at 1 ft	925 $\mu W/cm^2$	2313 $\mu W/cm^2$	3469 $\mu W/cm^2$

The high level of UV irradiance from these three lamp wattages make them likely "false alarm" sources. Their UV and IR irradiances in the bands of interest will be determined in the Donmar laboratory measurements. Additional spectra are given in Figures 8 and 9.

The warmup time for metal halide lamps can take up to 6 minutes. The restrike time can take up to 15 to 20 minutes, necessitating a period of cooling to reduce internal pressure before an arc is restruck again and grows to full brightness. This is one serious disadvantage to their use, unless temporarily substituted for by alternative backup sources as discussed below.

c. Mercury Vapor Lamps

As with the other HID lamps, high pressure mercury vapor lamps are made with an inner arc tube and an outer bulb. The arc tube is made of quartz. It therefore is highly transmissive in the UV region down to its UV cutoff well below 185 nm, and in the IR region up to its cutoff around 7 μM. It can itself be at temperatures as high as 1100°C. The outer bulb typically is borosilicate glass, likewise transmissive to its cutoff in the UV and IR regions.

Since mercury has a low vapor pressure at room temperature, and even lower at cold temperatures, a small amount of

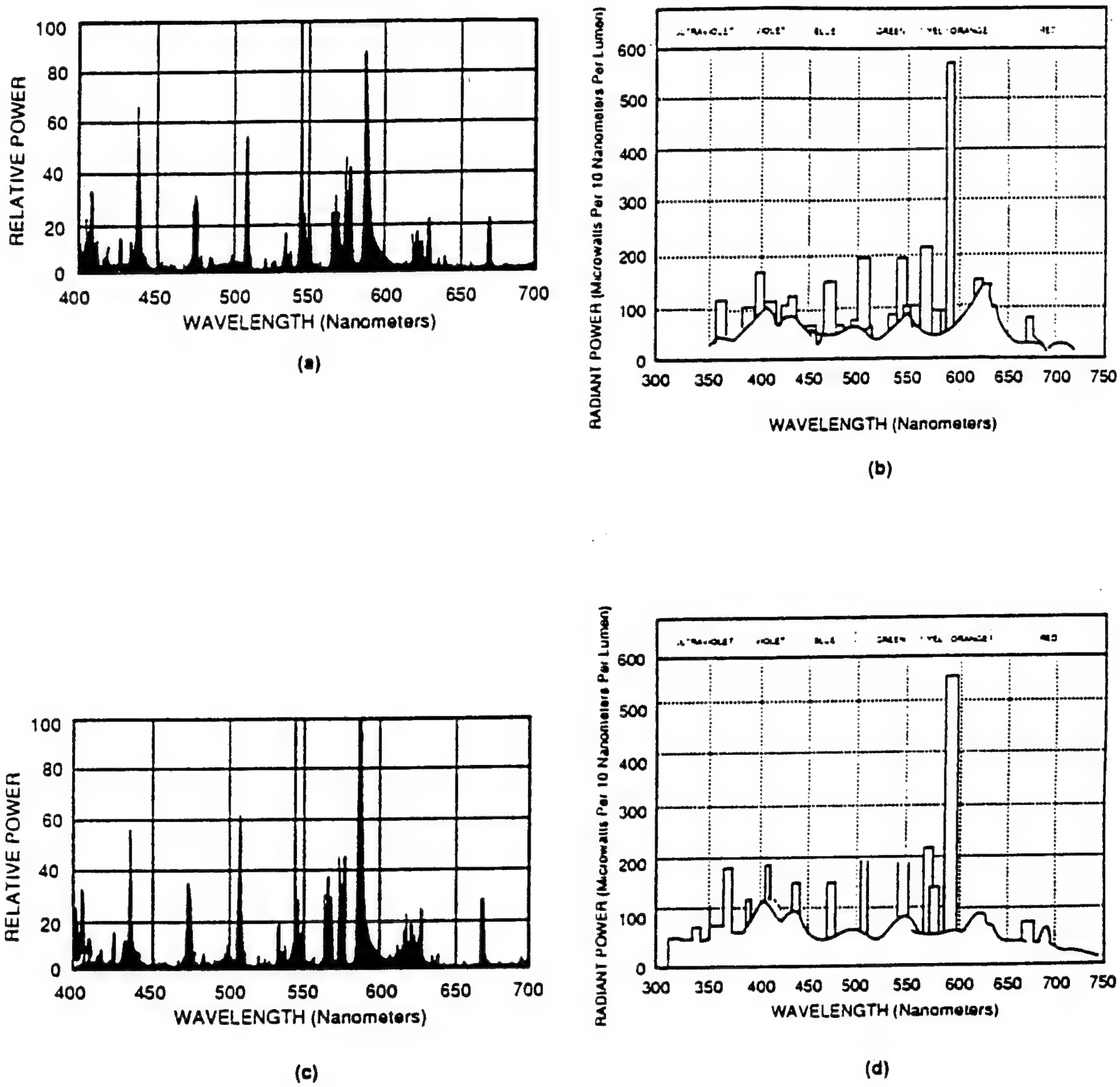
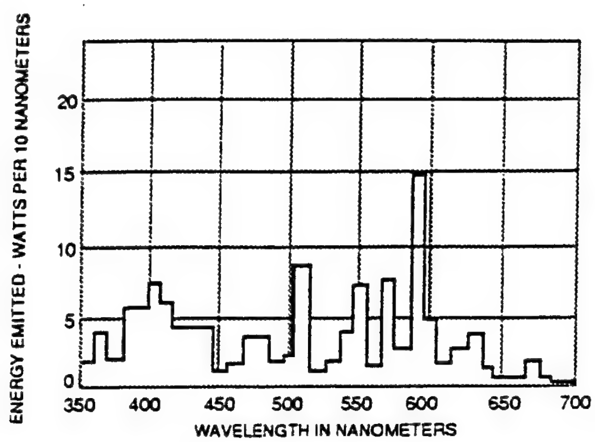
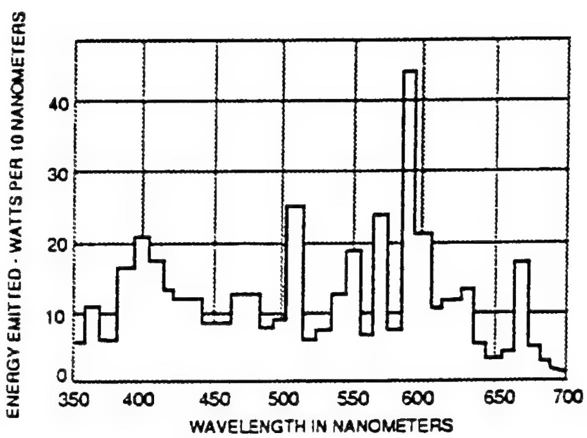


Figure 6. High Pressure Metal Halide Lamps Spectral Output: (a) and (b): Metal Halide Lamps-Clear; (c) and (d): Metal Halide Lamps-Phosphor Coated

(a) 400 Watt Metalare clear lamp





(b) 1000 Watt Metalare Clear Lamp

(c) 1500 Watt Metalare Clear Lamp

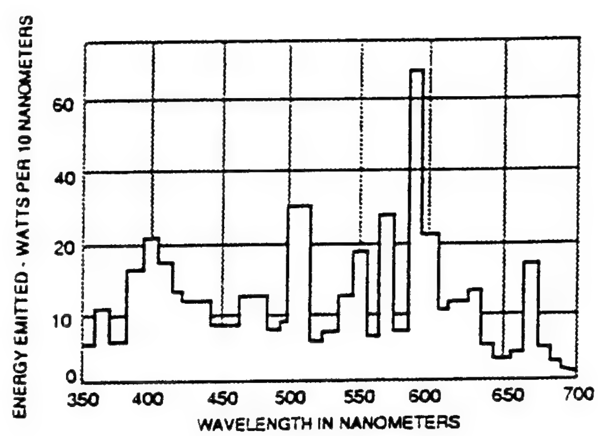
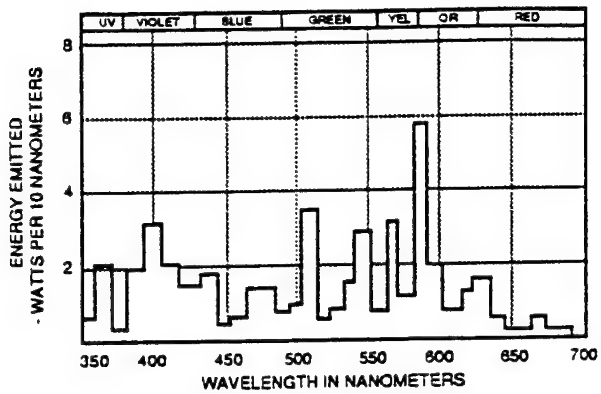
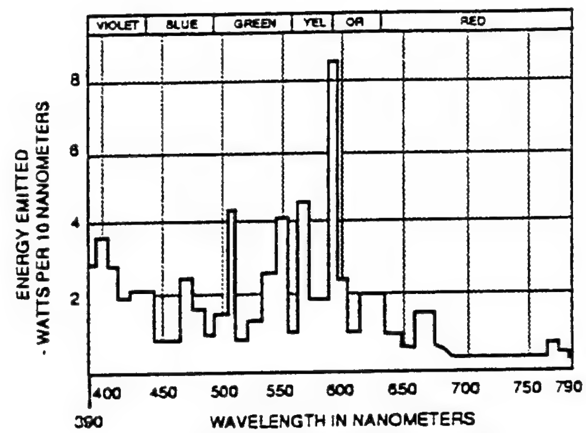


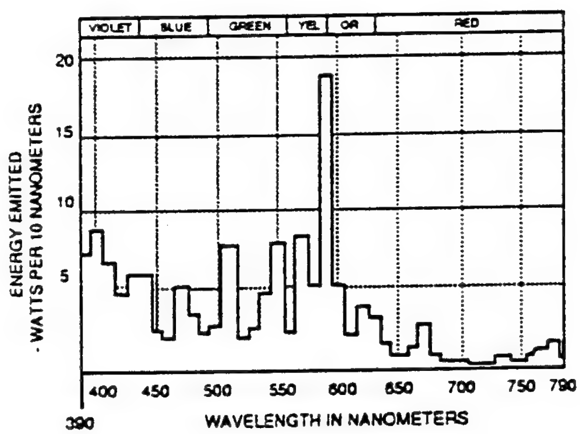
Figure 7. Spectral Energy Distribution of Several Different Powers of Metalare Metal Halide Lamps



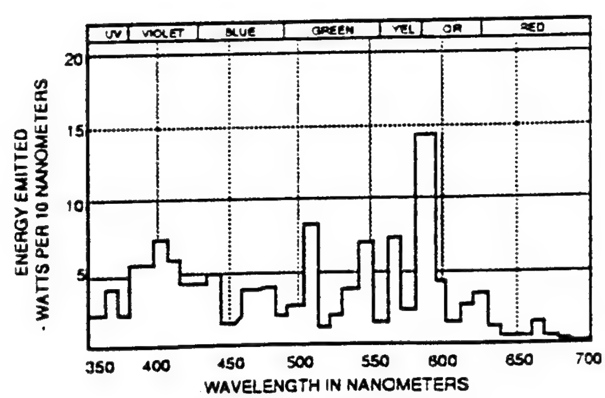
(a) 175-Watt Metalarc Clear Lamp



(b) 250-Watt Metalarc Clear Lamp

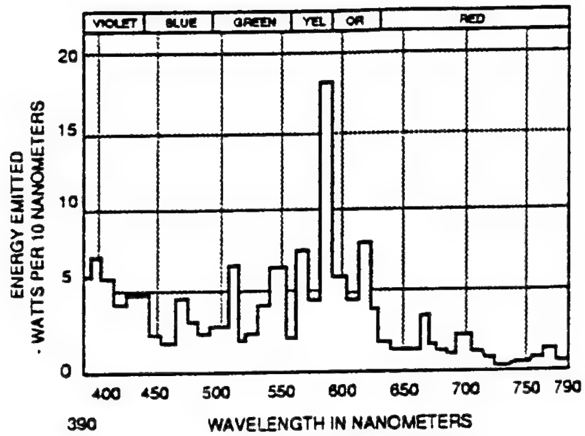


(c) MS400/HOR Clear Lamp

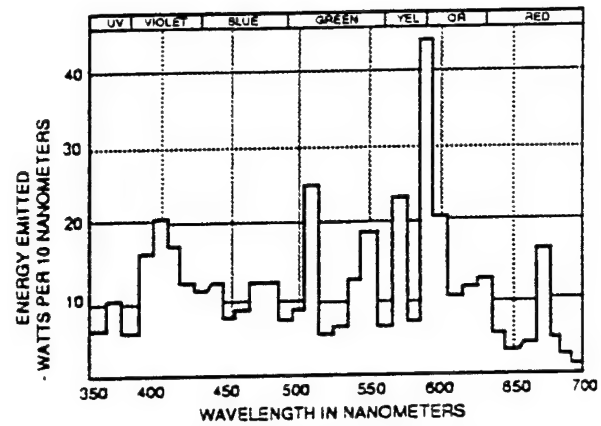


(d) 400-Watt Metalarc Clear Lamp

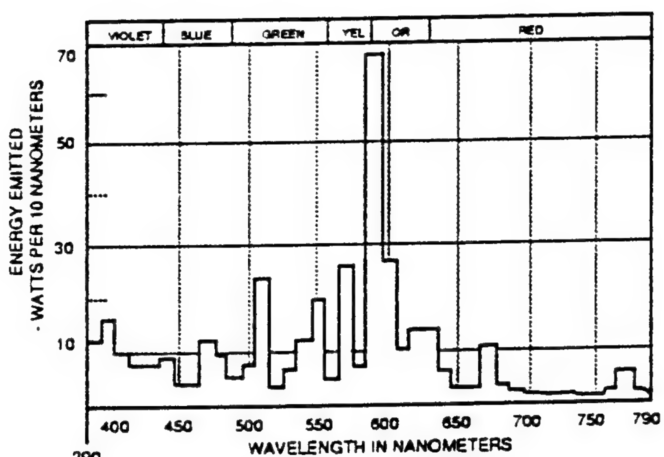
Figure 8A. Spectral Energy Distribution of Metal Halide Lamps



(e) MS400/C/HOR Metalarc/C Lamp

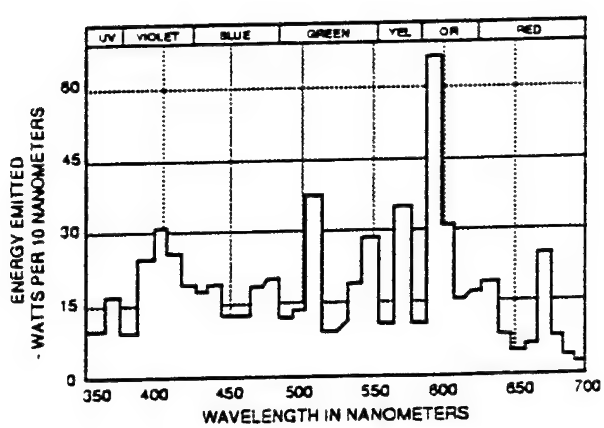


(f) 1000 -Watt Metalarc Clear Lamp



(g) MS 1000 Super Metalarc Lamp

Figure 8B. Spectral Energy Distribution of Metal Halide Lamps (Continued)



(h) 1500-Watt Metalarc Clear Lamp

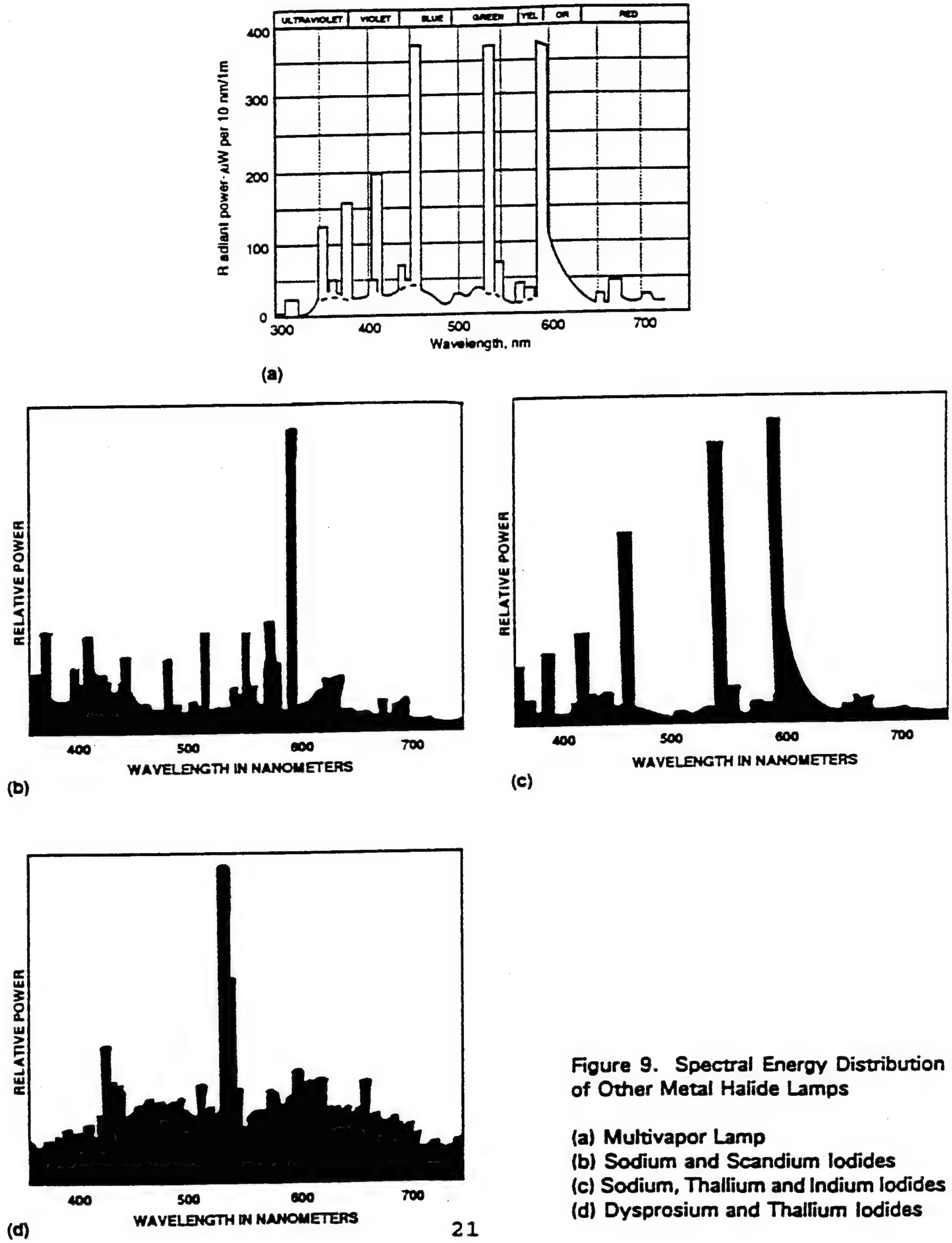


Figure 9. Spectral Energy Distribution of Other Metal Halide Lamps

(a) Multivapor Lamp
(b) Sodium and Scandium Iodides
(c) Sodium, Thallium and Indium Iodides
(d) Dysprosium and Thallium Iodides

more readily ionized argon gas is introduced to facilitate starting. Once the arc strikes, its heat begins to vaporize the mercury, continuing until all the mercury is evaporated. The amount of mercury in the lamp (around 50 mg) essentially determines the final operating pressure, which is usually 2 to 4 atmospheres in the majority of lamps. Between the arc tube and outer bulb, an inert gas, generally nitrogen, is used to prevent oxidation of internal parts.

Ultraviolet radiation as applied to biological effects is divided into three regions: (1) UV-A or "longwave" ultraviolet from 320 to 400 nm; (2) UV-B or "shortwave" ultraviolet from 280 to 320 nm; and (3) UV-C or "extreme" ultraviolet from 180 to 280 nm. Figure 10 shows the relative spectral line distribution of energy emitted by ozone-producing germicidal low pressure mercury lamps. Such lamps have an enclosing bulb that is UV transmissive. The figure shows how the three UV regions relate in output.

In the high pressure mercury vapor lamp, however, its pressure accounts for its characteristic spectral power distribution. In general, higher operating pressure tends to shift a larger proportion of emitted radiation into longer wavelengths. At extremely high pressure there is also a tendency to spread the line spectrum into wider bands. This is seen in Figure 11. The use of borosilicate glass for the outer bulb also is to filter out the UV-B and UV-C radiation. The spectral output of various mercury lamps is shown in Figures 12 through 15.

In the visible region, the five principal lines are at 404.7, 435.8, 546.1, 577 and 579 nm, having the appearance of a greenish-blue light. While the overall light appears to be bluish-white, there is an absence of red radiation, especially in the low and medium pressure lamps, causing blue, green and yellow colors to be emphasized whereas orange and red appear brownish. The "color-rendering" capability of mercury lamps is improved by coating the interior of the outer bulb with phosphors, similarly as is done in fluorescent lamps. This is done in the case of a mercury vapor HID lamp used in the older version of the NF2 lightall unit shown in Figure 14.

Designated as a Philips H33GL-400/DX lamp, a vanadate phosphor, which emits orange-red radiation, is used to coat the inner surface of the outer bulb. It results in a light output of white corresponding to 4000°K and hence the suffix "/DX" is added, which symbolizes a "deluxe white phosphor." See also Figure 15(d).

One HID lamp that is a mercury vapor lamp used in the Edwards AFB hangars is the 1000 watt GE lamp: HR 1000 A36-15, to be used with the ANSI specification H15 or H36 ballast. It is a "clear" lamp without any phosphor coating.

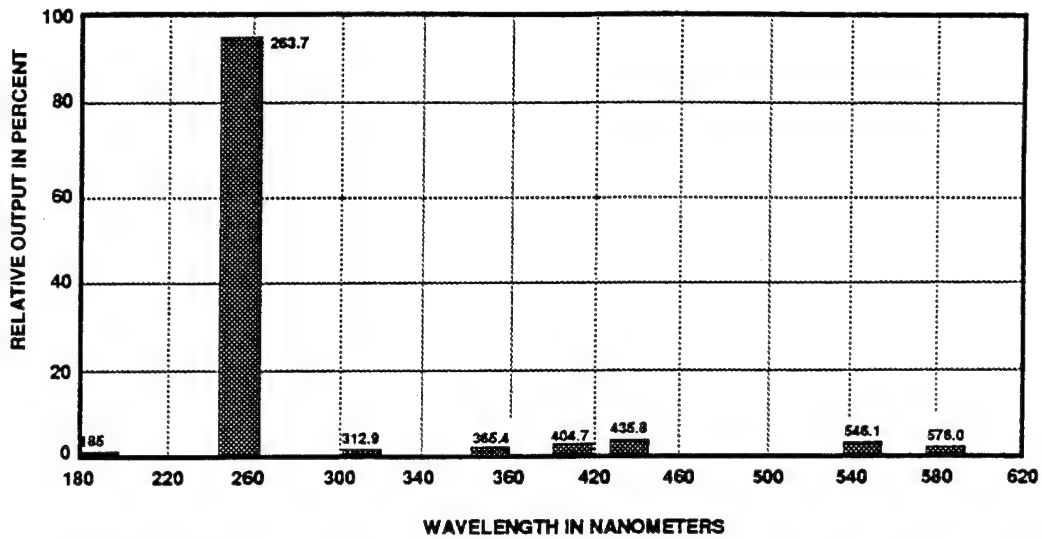


Figure 10. Relative Spectral Distribution of Energy Emitted by Ozone Producing Germicidal Lamps.

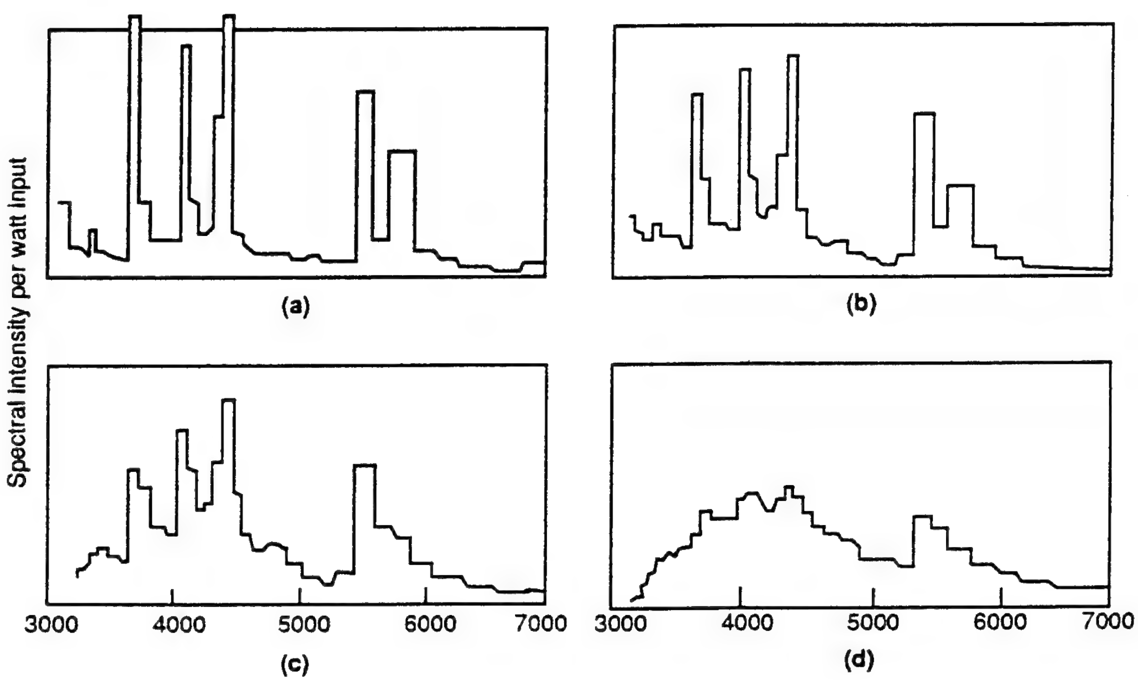
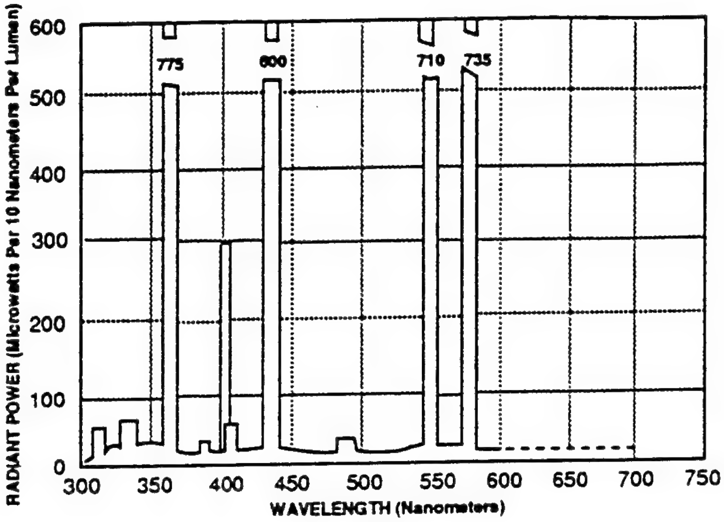
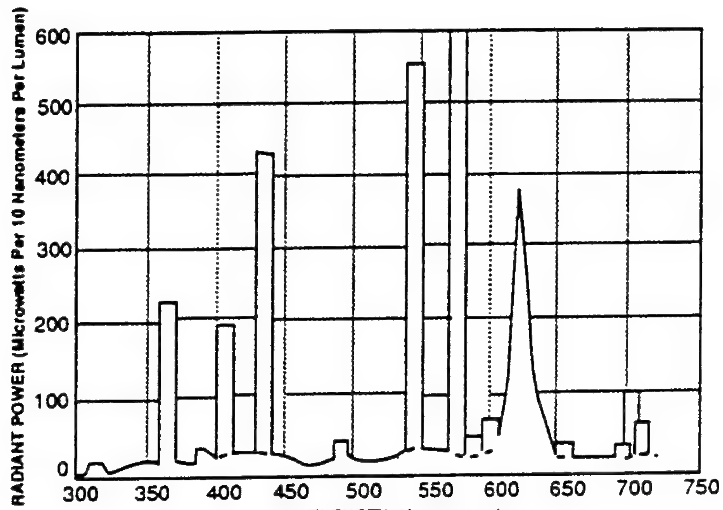


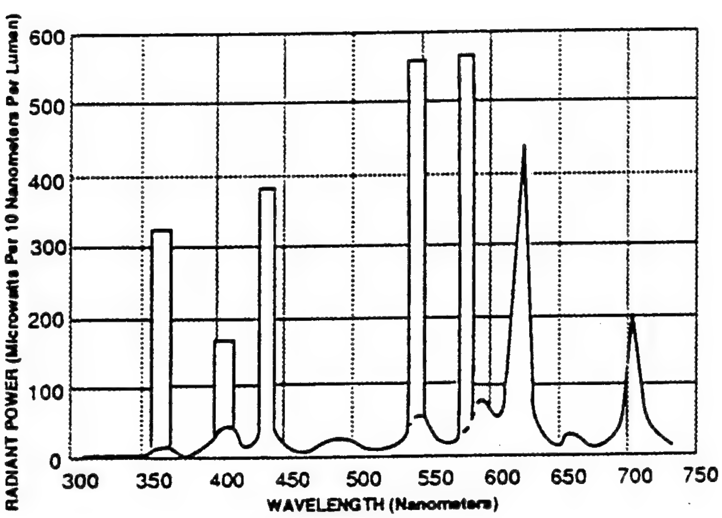
Figure 11. Emission Spectrum of High-Pressure Mercury-Arc Lamps Showing Continuous Background



(a)

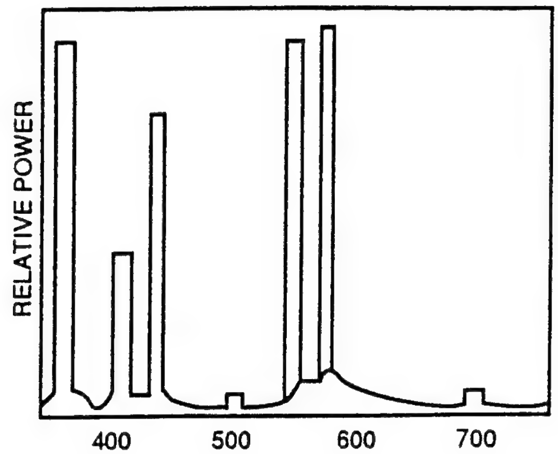


(b)



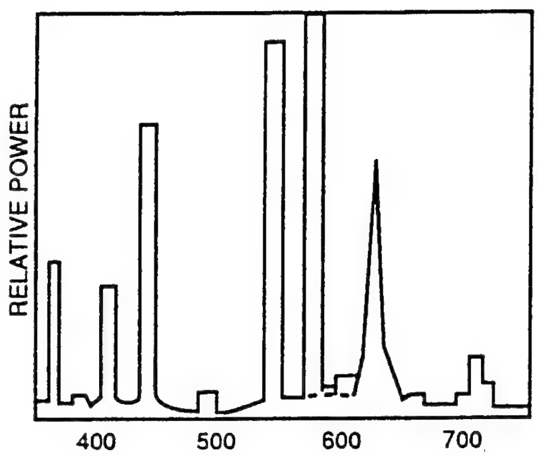
(c)

Figure 12. Spectral Output of High Pressure Mercury Lamps (a) Clear, (b) Deluxe, (c) Warm Deluxe



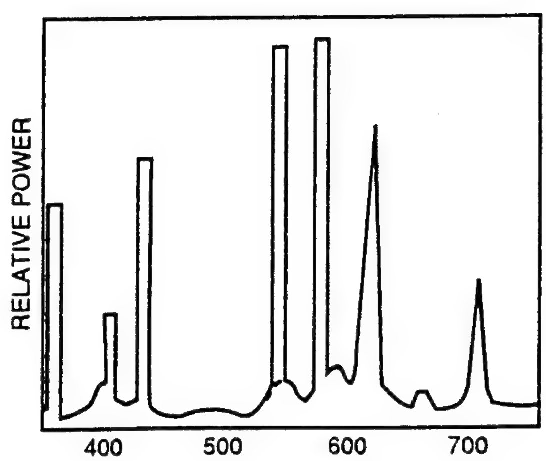
(a)

CLEAR MERCURY 5900 K



(b)

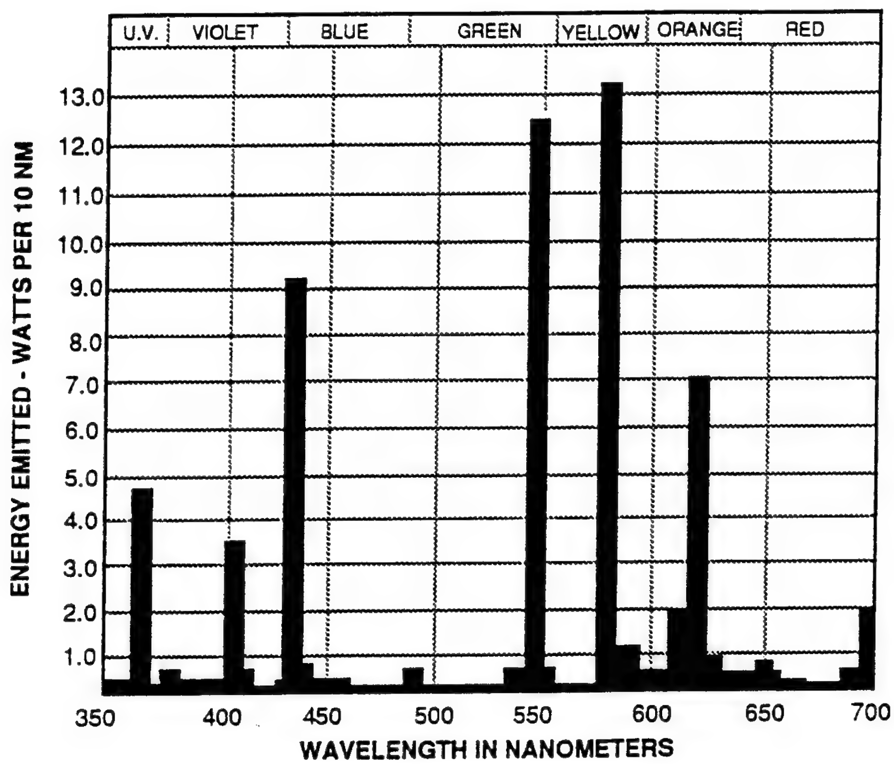
PHOSPHOR-COATED 4000K (DX)



(c)

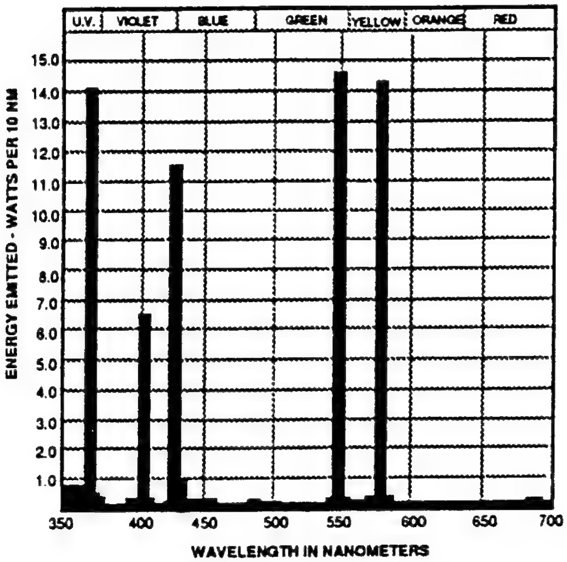
PHOSPHOR-COATED 3600K (WDX)

Figure 13. Mercury Lamp Spectrum: Different Coatings



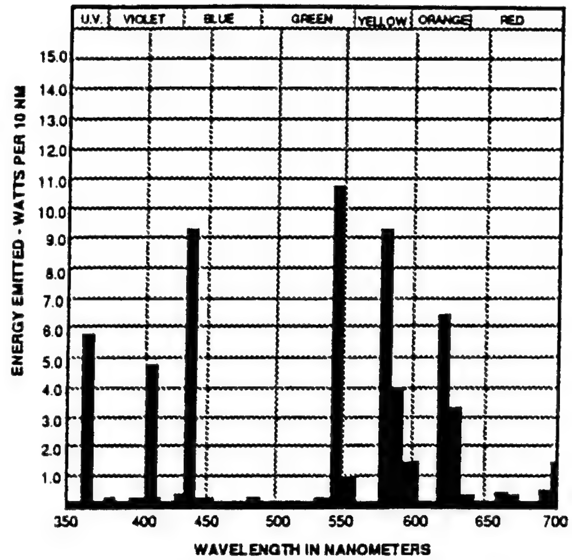
Correlated Color Temperature - 4000°K
Color Rendering Index - 43
CIE Chromaticity - x = .382 y = .385

Figure 14. Age Lightall Lamp: Spectral Energy Distribution of 400 - Watt Brite-White Deluxe Mercury Lamp (H33GL - 400/DX), Used on Older NF-2 Units.



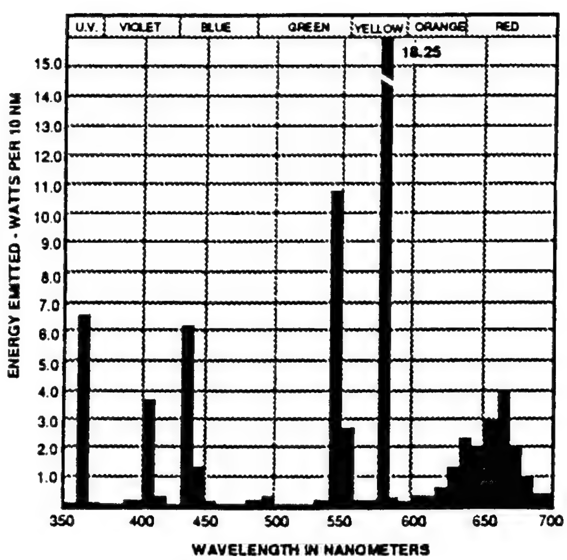
Correlated Color Temperature - 5900°K
Color Rendering Index - 22
CIE Chromaticity - x = .320 y = .379

FIGURE (a) Spectral energy distribution of 400 - Watt Clear Deluxe mercury lamp (H33CD-400).



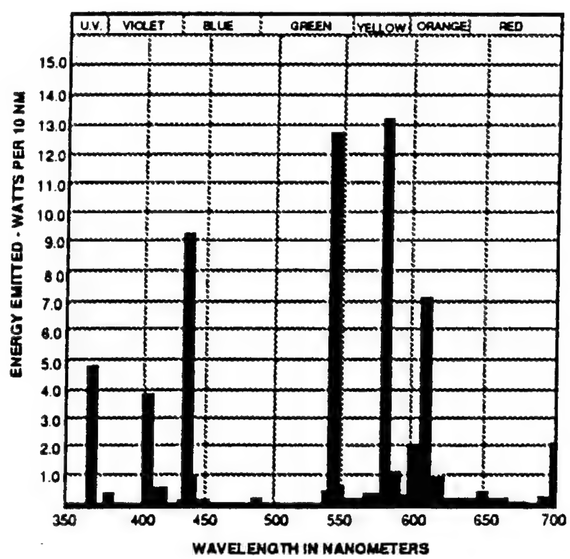
Correlated Color Temperature - 3600°K
Color Rendering Index - 47
CIE Chromaticity - x = .400 y = .380

FIGURE (c) Spectral energy distribution of 400 - Watt Warm Deluxe mercury lamp (H33GL-400/WDX).



Correlated Color Temperature - 4200°K
Color Rendering Index - 45
CIE Chromaticity - x = .383 y = .419

FIGURE (b) Spectral energy distribution of 400 - Watt Color Improved mercury lamp (H33GL-400/C).



Correlated Color Temperature - 4000°K
Color Rendering Index - 43
CIE Chromaticity - x = .382 y = .385

FIGURE (d) Spectral energy distribution of 400 - Watt Brite-White Deluxe mercury lamp (H33GL-400/DX)

Figure 15. Spectral Energy Distribution and Other Characteristics of Mercury Vapor Lamps

The 400 watt mercury vapor lamp used in the older NF2 2-lamp lightall unit is a Philips lamp as described above, designated: H33GL-400/DX, to be used with the ANSI specification H33 ballast.

The energy output of the 400 watt mercury vapor lamp is as follows:

Table 5

Type of Energy	400 Watt Mercury Vapor Lamp	
	Including Ballast	Excluding Ballast
Visible	14.6%	16.1
Infrared	46.4	51.1
Ultraviolet	1.9	2.1
Conduction/convection	27.0	29.7
Ballast	10.0	--

The UV radiance for the 400 watt lamp is about 7.6 watts, the radiant intensity is about 0.6046 watts/ster, and the irradiance at 1 foot distance is about 651 $\mu W/cm^2$. The IR radiance is about 204 watts, the radiant intensity is about 14.77 watts/ster, and the irradiance about 1.59×10^4 $\mu W/cm^2$ at 1 foot distance.

For the 1000 watt mercury vapor lamp, the light output is about 2.5 times that of the 400 watt lamp. Scaling the above values accordingly, the UV radiance is estimated to be 19 watts, the radiant intensity 1.51 watts/ster, and the irradiance 1627 $\mu W/cm^2$ at a 1 foot distance.

Depending upon the distance, both lamps are capable of contributing to or causing a false alarm.

The warmup time for the mercury vapor lamps is up to about 4 minutes. The restrike time is from about 3 to 10 minutes.

Because of the unique characteristics of HID lamps to require several minutes warmup time, to turn off with small drops in line voltage, and to require one to several minutes of restrike time to return to normal operation, it is advisable to supplement them with an alternative light source for such down times.

d. Short-Arc Lamps

Short arc lamps of the types summarized in this section are not commonly used as hangar lights at Edwards AFB, although they may be used in other locations.

These lamps include xenon, mercury-xenon and mercury-argon high pressure discharge lamps, and are characterized by short arc discharges. See Figures 16 through 25.

Table 6

Short-arc Lamps

			Lamp Watts	Approx. Lumens	Average Luminance cd/mm^2
1)	Xenon:	(vertical)	300	7,600	200
		(horizontal)	350	9,000	440
		(vertical)	1000	37,000	600
		(horizontal)	1000	35,000	450
		(vertical)	5000	210,000	600
		(no horizontal)	5000	--	--
2)	Mercury-Xenon:		350	19,500	500
		(vertical only)	1000	50,000	250
			5000	265,000	860
3)	Mercury-Argon:		350	21,000	590
		(vertical only)	1000	60,000	140

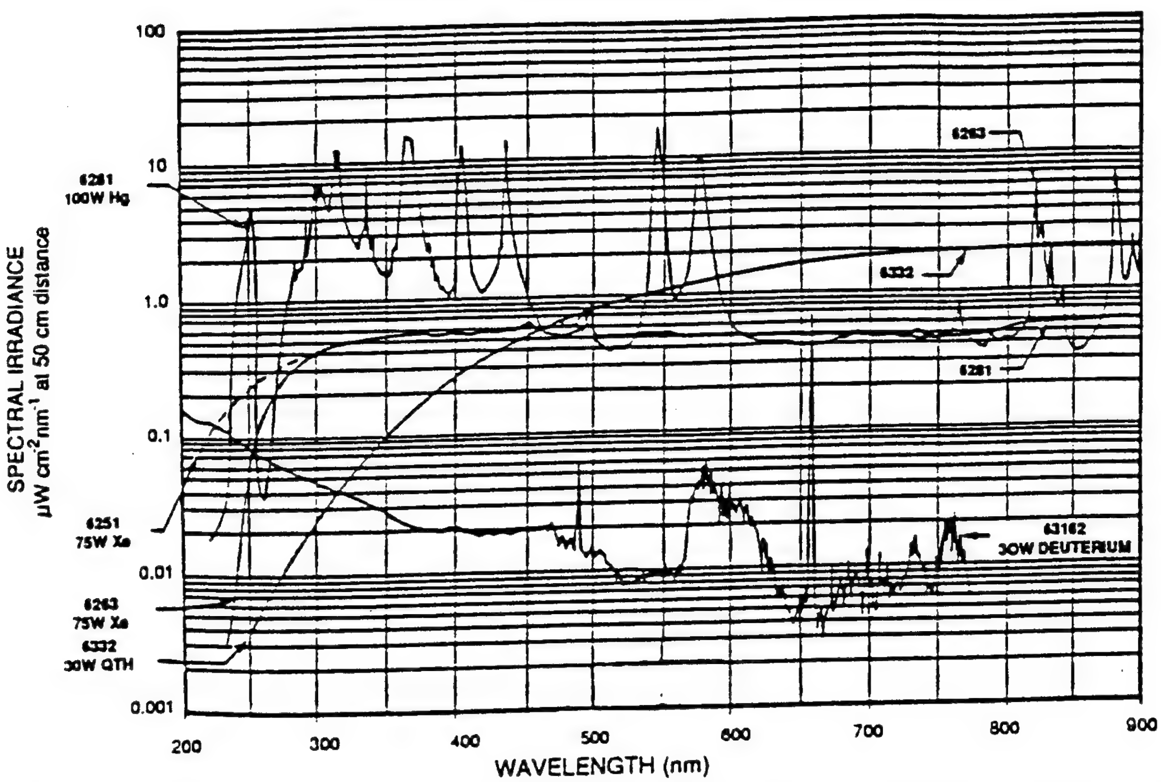
e. Low Pressure Lamps

(1) Low Pressure Sodium Lamps (See Figure 26)

	Lamp Watts	Approx. Lumens
(1) L72RD-90 (ANSI):	90W	13,500
(2) 1R74RF-180 (ANSI):	180W	33,000

(2) Low Pressure Discharge Lamps (See Figure 27)

	Lamp Watts	Approx. Lumens
(1) Pencil type Spectral lamps Mercury (Argon)	1.98W	90% of output= 253.7nm at 18mA 30% of output = 253.7nm at 30 Ma, rest in inside lines
Mercury (Neon)	1.98W	Hg spectrum +Ne lines in 330-360, 530-760nm regions



To approximate the irradiance of other lamps: 6282 50 W Hg: multiply 100 W Hg lamp by 0.5; 10 W Qth: multiply 50 W QTH lamp by 0.06; 20 W QTH: multiply 50 W QTH lamp by 0.13

Figure 16. Spectral Irradiance of Low Wattage Hg, Xe, QTH and Deuterium Lamps.

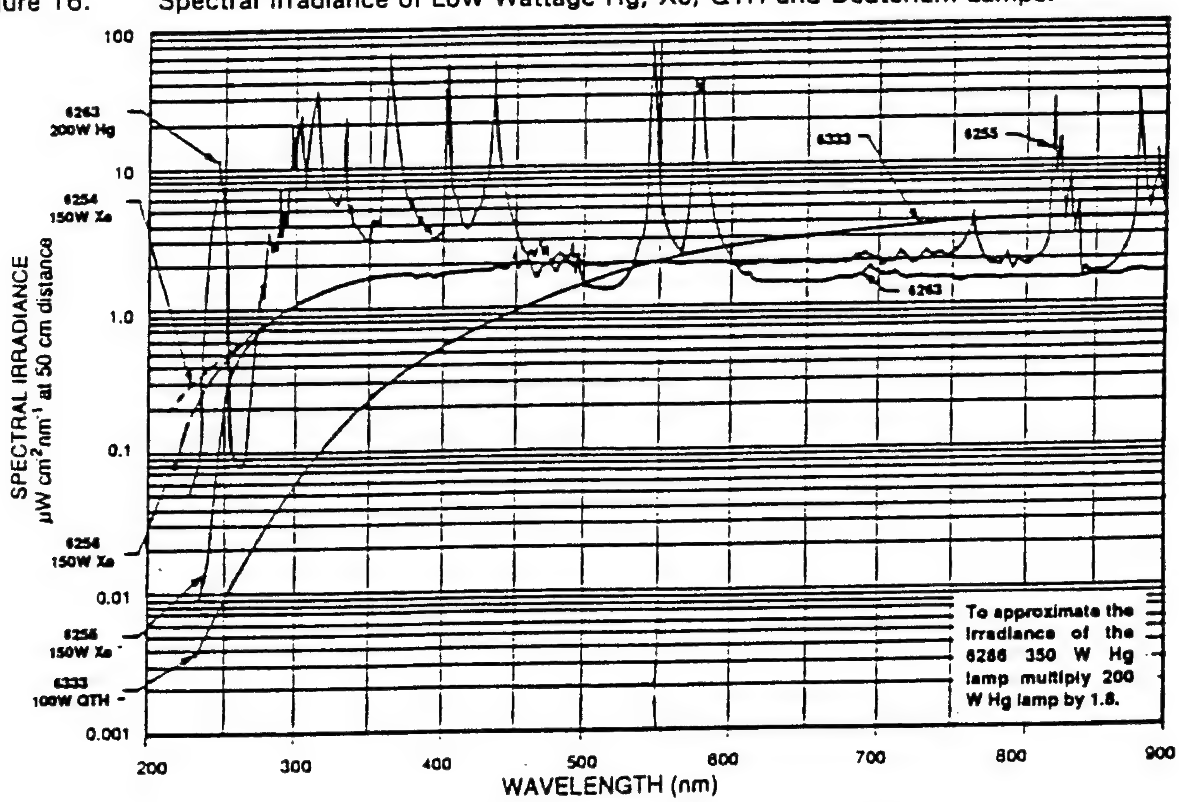


Figure 17. Spectral Irradiance of 200 W Hg, 150 Xe, and 100 W QTH Lamps.

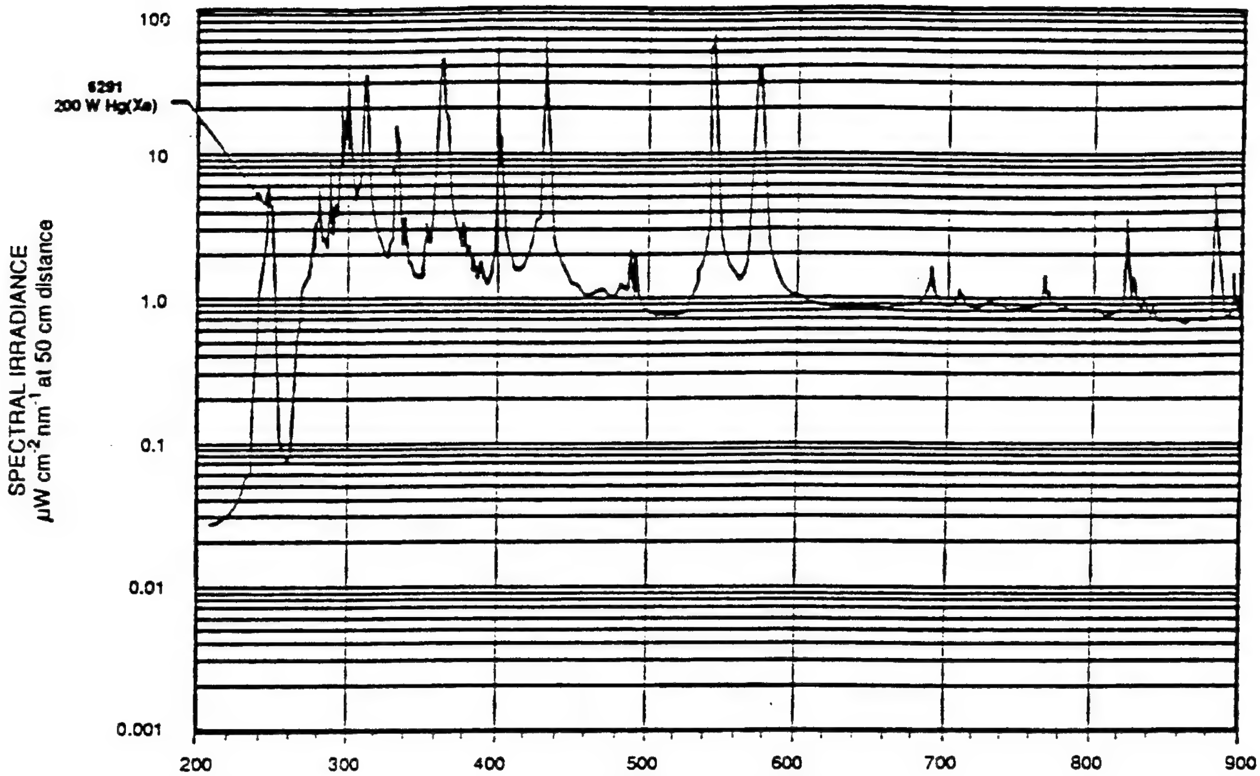


Figure 18. Spectral Irradiance of 200 W Hg (Xe) Lamp

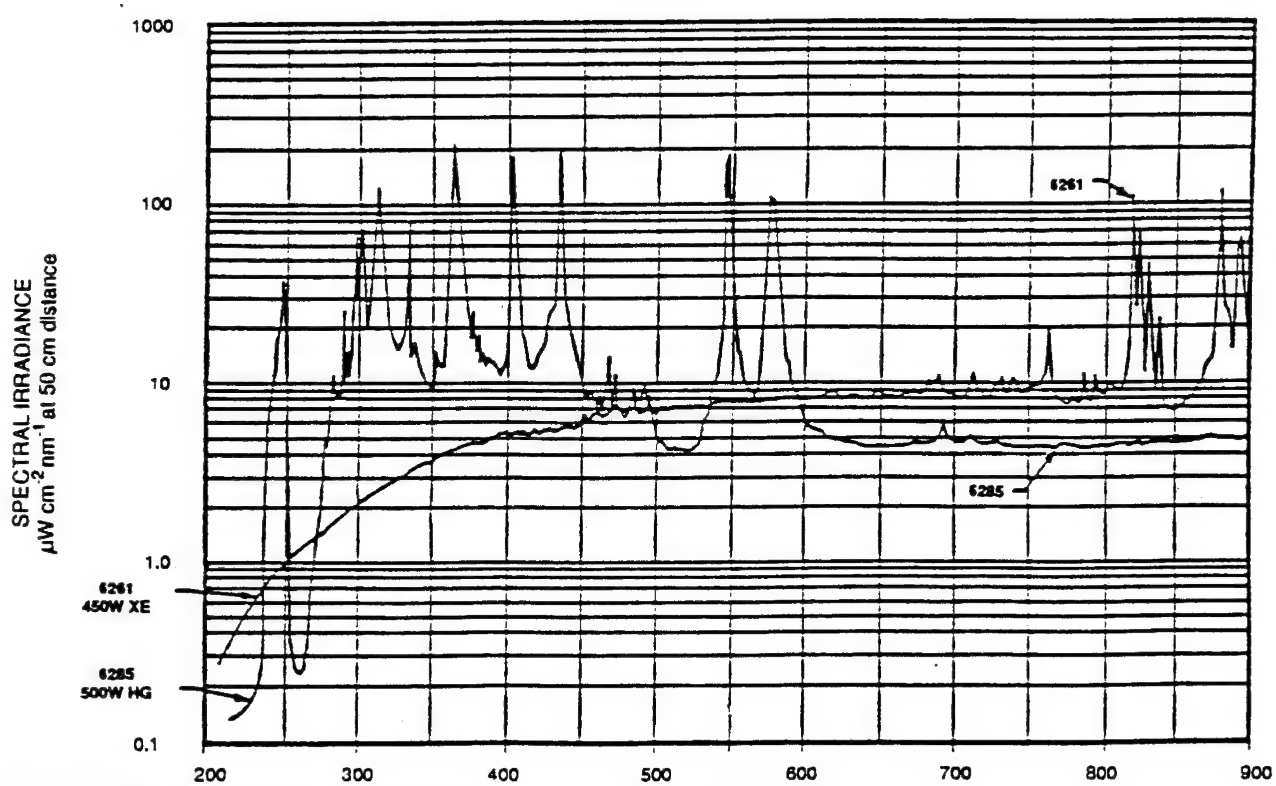


Figure 19. Spectral Irradiance of 450W Xe and 500W Hg Lamps

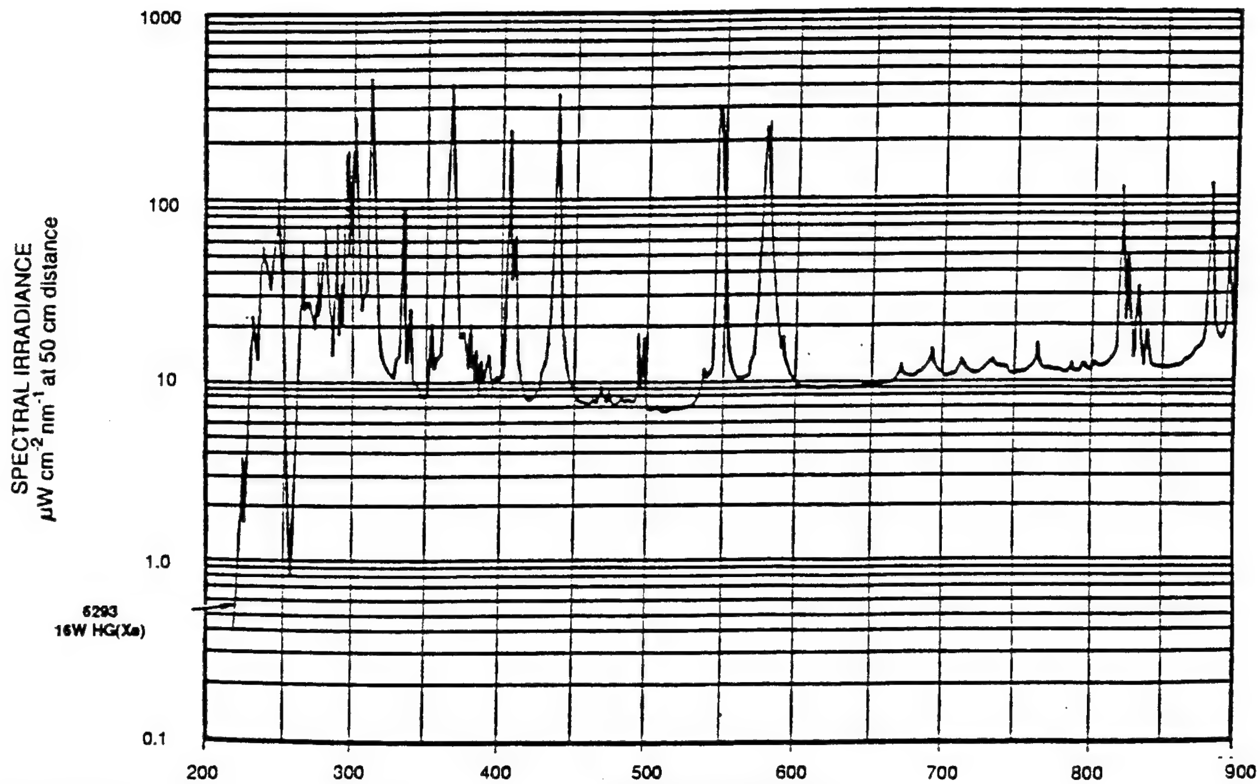


Figure 20. Spectral Irradiance of High Power Hg, Xe, and QTH Lamps

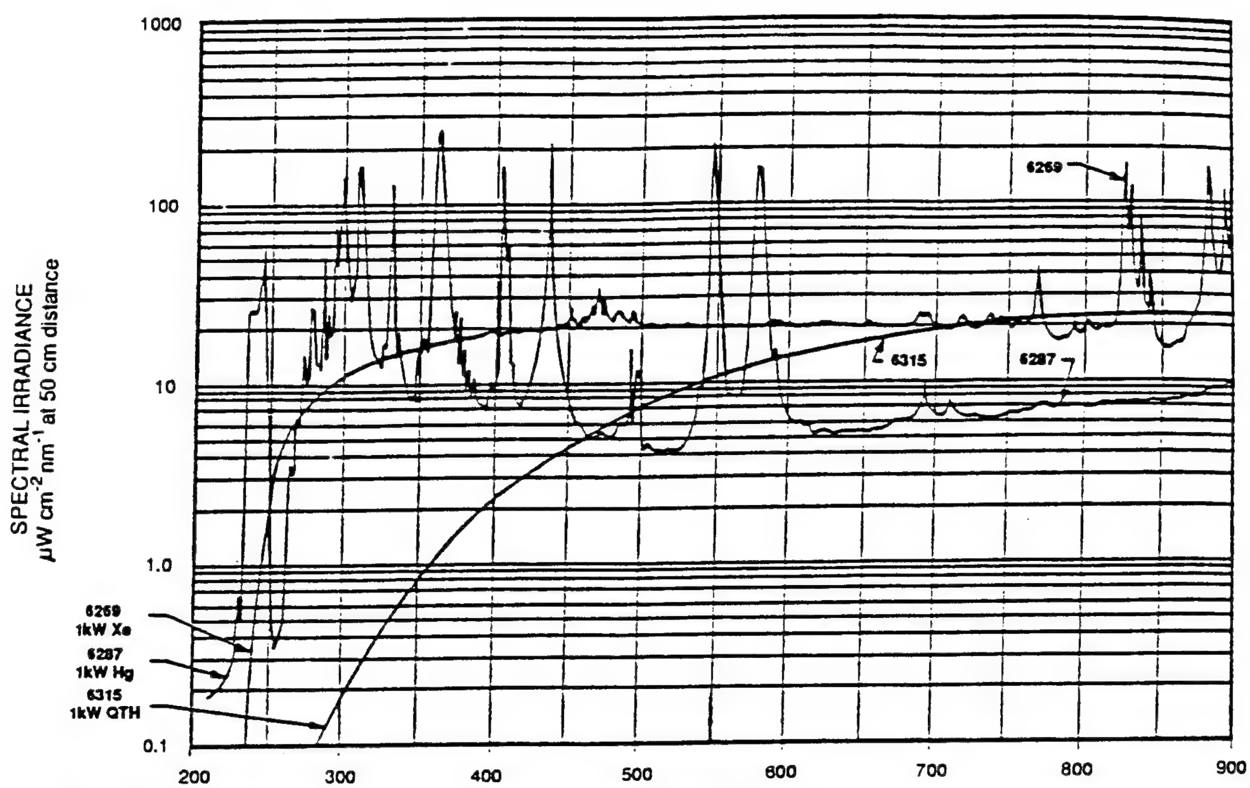


Figure 21. Spectral Irradiance of 1000 W Hg (Xe) Lamp

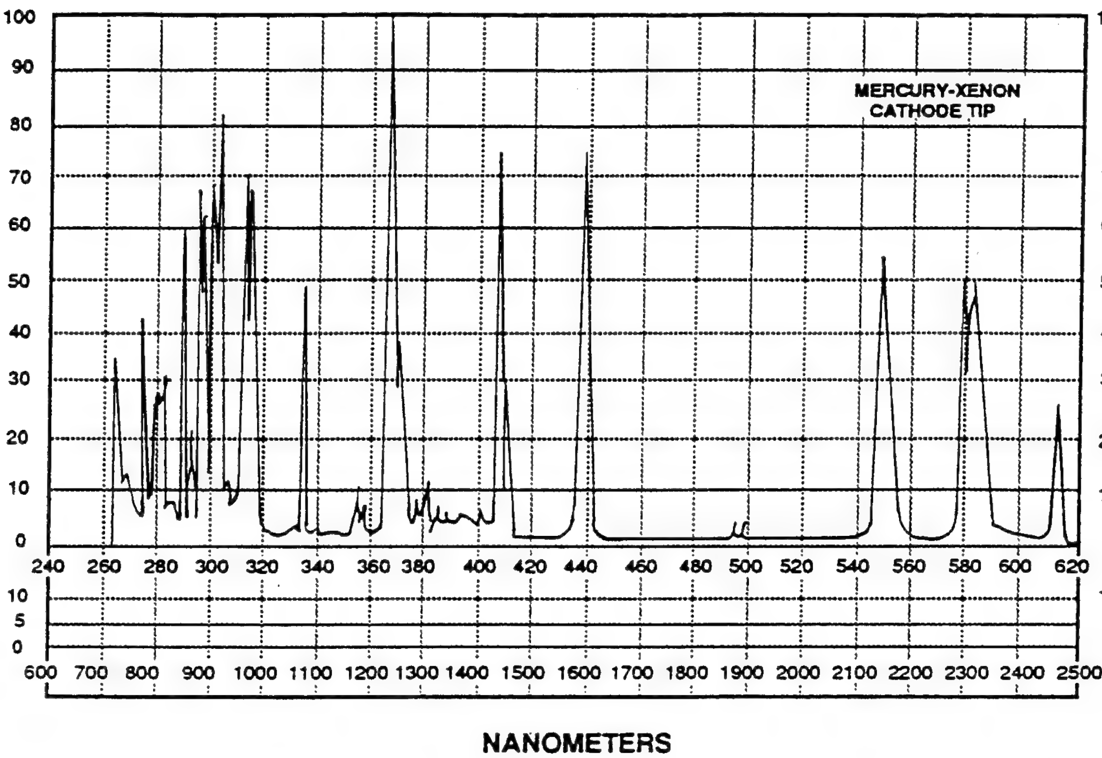


Figure 22. Mercury-Xenon Compact Arc Lamps

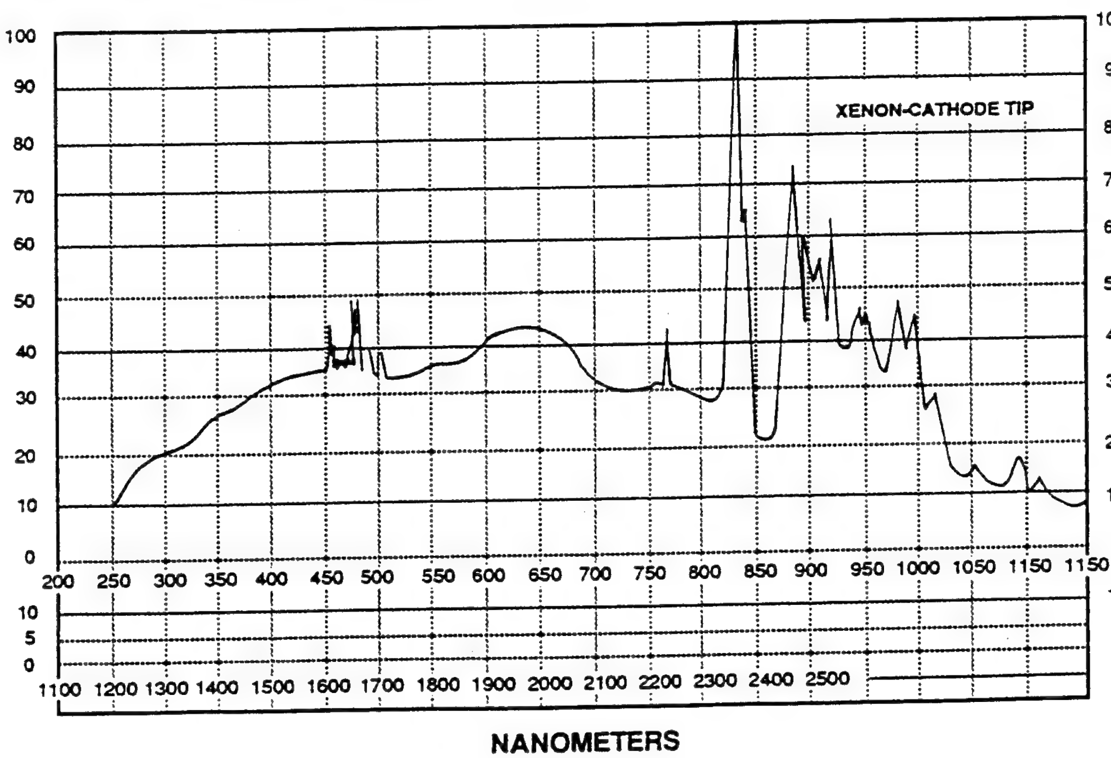


Figure 23. Xenon Compact Arc Lamps

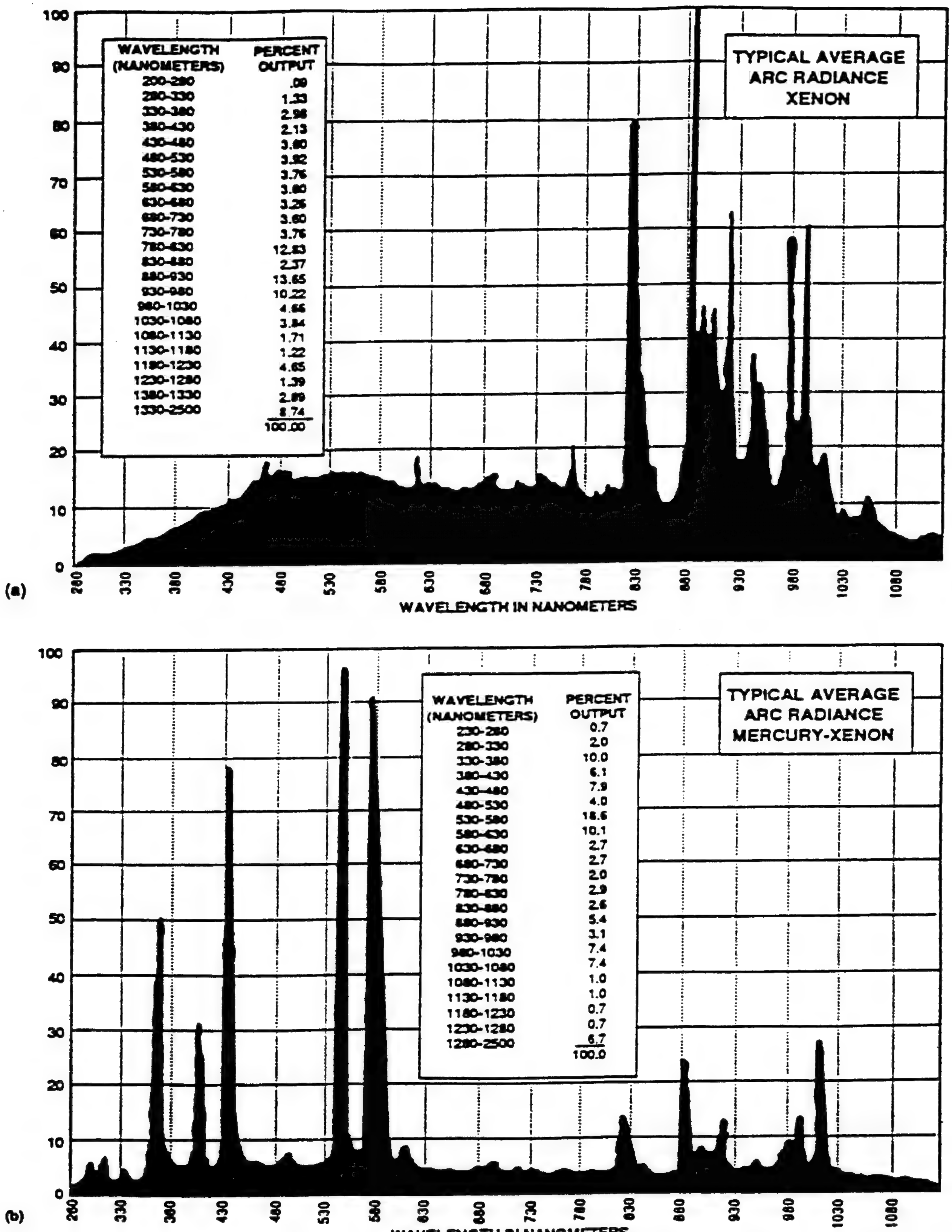


Figure 24. Spectral Radiance Distribution of (a) Xenon and (b) Mercury Xenon Arc Lamps

Wavelength (Nanometers)	Percent Output
230-280	0.7
280-330	2.0
330-380	10.0
380-430	6.1
430-480	7.9
480-530	4.0
530-580	18.6
580-630	10.1
630-680	2.7
680-730	2.7
730-780	2.0
780-830	2.9
830-880	2.6
880-930	5.4
930-980	3.1
980-1030	7.4
1030-1080	7.4
1080-1130	1.0
1130-1180	1.0
1180-1230	0.7
1230-1280	0.7
1280-2500	6.7
	100.0

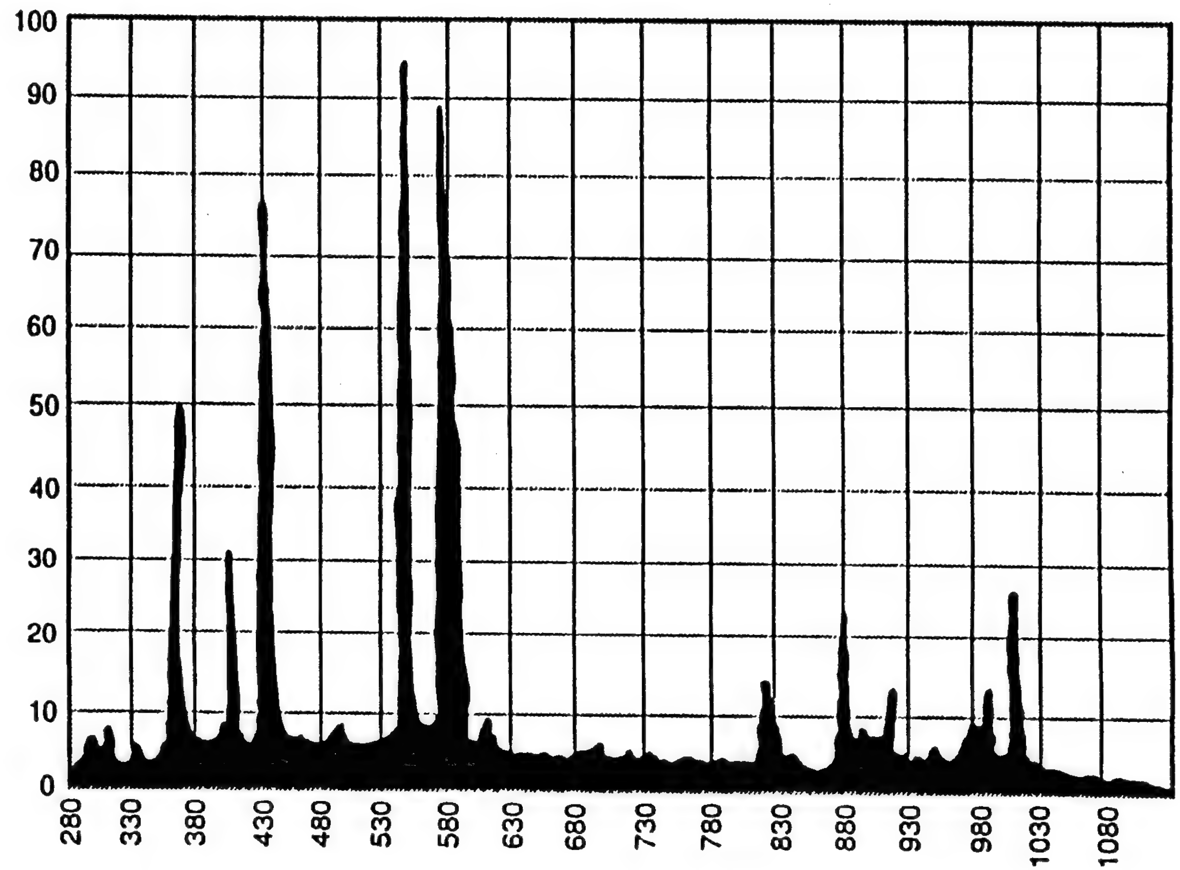


Figure 25.Typical Spectral Distribution-Mercury-Xenon

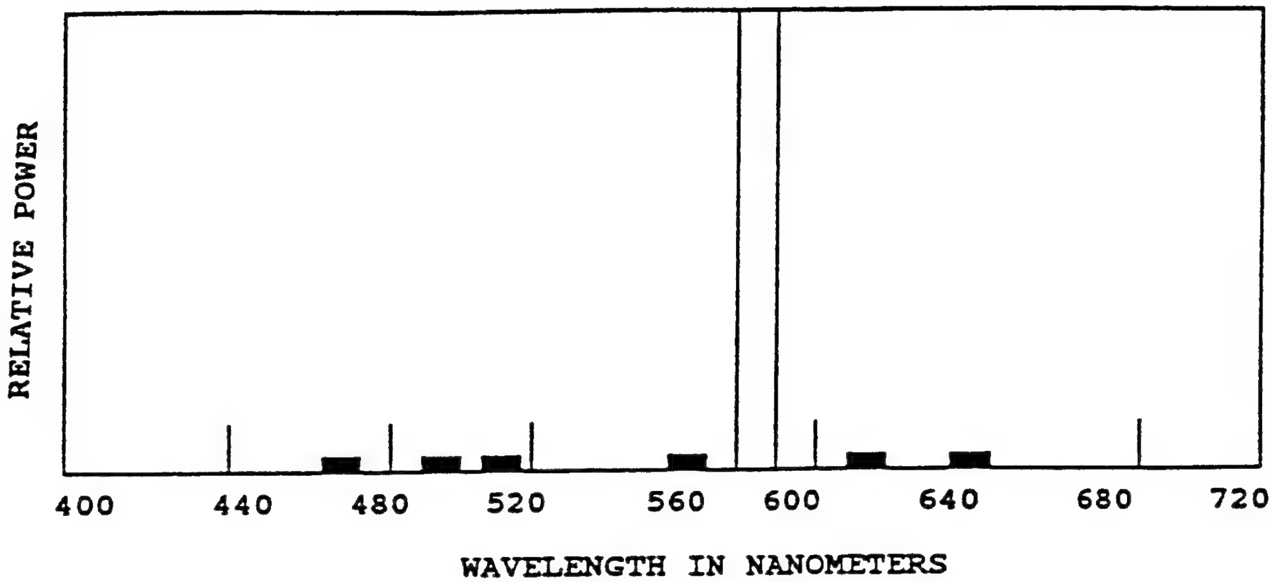
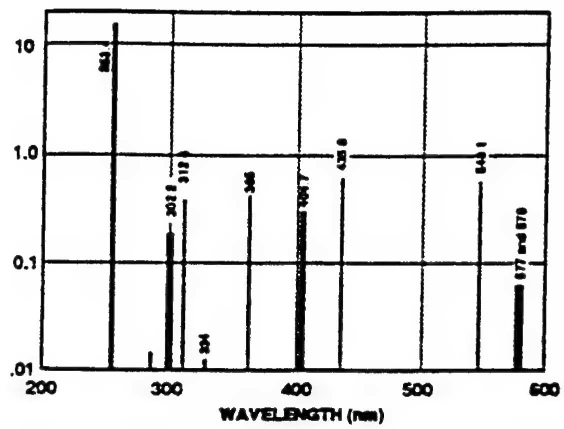
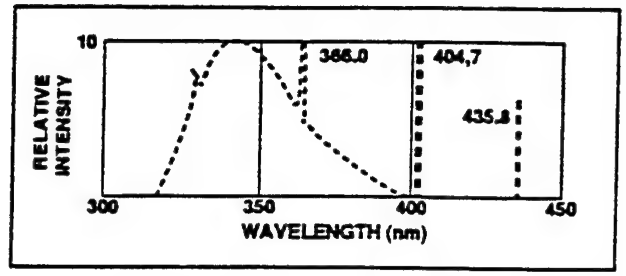


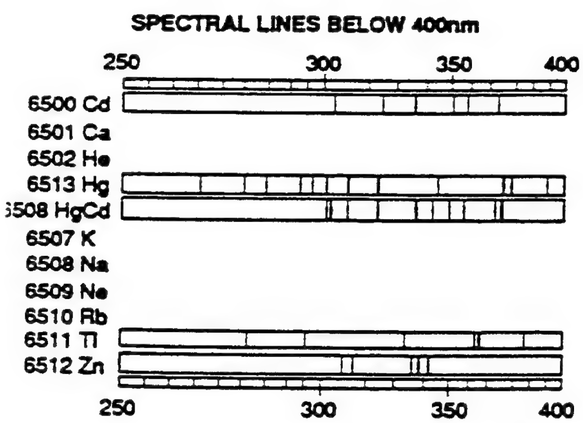
Figure 26. Low Pressure Sodium Lamps



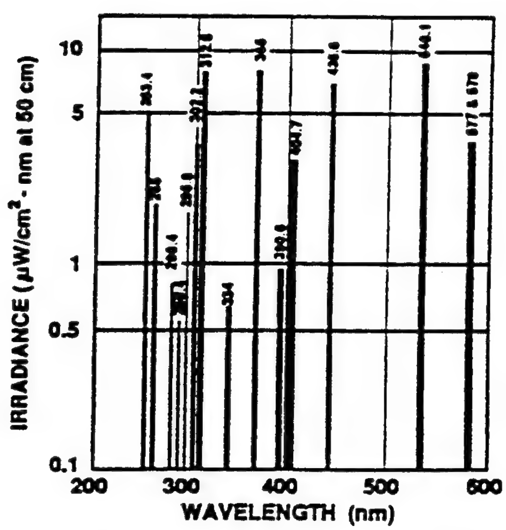
(a) Typical irradiance at 50 cm from 6035 Lamp (HG (AR)) at 18 mA.



(b) Emission of Hg (Ar) lamp with 6042 Long Wave Conversion Filter.



(c) Output spectra of Oriel Spectral Line Lamps.



(d) Irradiance at 50 cm from the 6513 Hg Lamp.

Figure 27. Low Pressure Discharge Lamps

(2) Spectral Calibration Lamps

Argon	2.7W
Krypton	2.7W
Neon	1.6W
Xenon	1.6W

(3) Spectral Line Lamps - High Power

	Power	Intensity (cd)
Cadmium	15W	1.2
Caesium	10	0.3
Helium	55	2.0
Mercury-Cadmium	25	10
Potassium	10	0.04
Sodium	15	40
Neon	30	3.5
Rubidium	10	0.2
Thallium	15	1.5
Zinc	15	0.5
Mercury	22-44	20-45

D. Fluorescent Lamps

The family of lamps second to the HID lamps as potential false alarm sources are the fluorescent lamps. The first major difference is that they are low pressure gas discharge lamps, all likewise having a small amount of mercury to generate UV radiation for exciting the phosphors coating the inner surface of the tubular lamps. They also have related warmup and restrike characteristics.

Commonly in use in Air Force buildings everywhere, but not as the hangar lights, their effect as false alarm sources is possible from nearby locations.

Divided into six basic types on the basis of white light output as determined by the phosphor coating, these are:

Table 7

Cool White	Deluxe Cool White
Warm White	Deluxe Warm White
White	Daylight

Manufacturers frequently use commercial names for marketing purposes, resulting in a wide variety of lamp names. Table 7 summarizes several lamp types manufactured by GTE Sylvania. Figure 28 shows the spectral output of several of these lamps.

For estimation of the IR energy output, the summary of the spectral distribution in Table 8 accounts for all the energy output of a Cool White lamp.

Table 8

Energy Output for Some Fluorescent Lamps of Cool White Color (Lamps Operated at Rated Watts on High Power Factor, 120-Volt, 2-Lamp Ballasts; Ambient Temperature 25°c (77°F) Still Air)

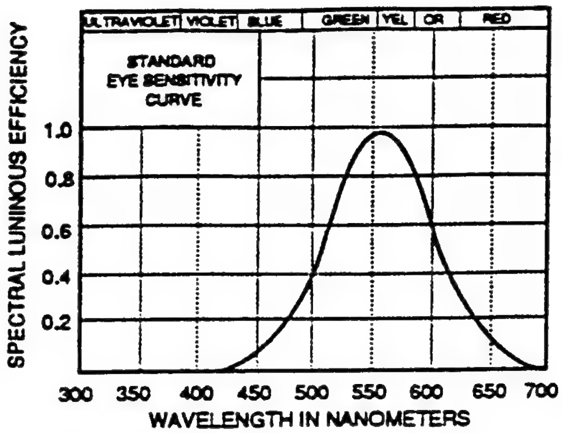
TYPE OF ENERGY	40WT12	96 INCH T12 (800 Ma)	PG17** (1500 Ma)	T12 (1500 Ma)
VISIBLE LIGHT	19.0%	19.4%	17.5%	17.5%
INFRARED (est.)*	30.7	30.2	41.9	29.5
ULTRAVIOLET	0.4	0.5	0.5	0.5
CONDUCTION-CONVECTION (est.)	36.1	36.1	27.9	40.3
BALLAST	13.8	13.8	12.2	12.2
APPROXIMATE AVERAGE BULB WALL TEMP.	41 C (106 F)	45 C (113 F)	60 C (140 F)	

* PRINCIPALLY FAR INFRARED (WAVELENGTHS BEYOND 5000 NANOMETERS).
** GROOVES SIDEWAYS

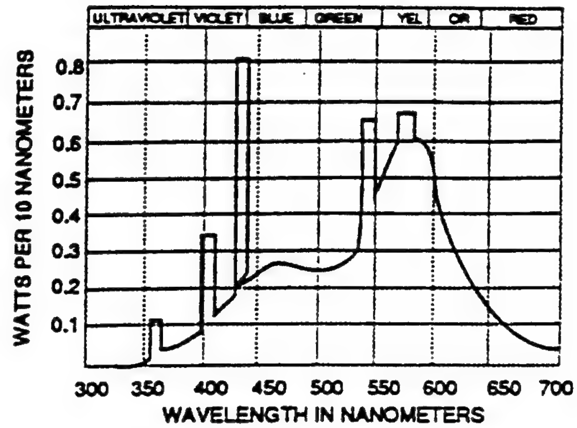
It was noted at Edwards AFB that the 96 inch fluorescent lamp was used extensively, and that the cool white type was used more commonly. But the warm white lamp also was used, sometimes in combination with the cool white lamp.

Approximately 60% of the input energy in a cool white lamp is converted directly into UV, with 38% going into the IR region, and only 2% into visible light. Figure 29 shows how the input energy of a 40 watt fluorescent lamp partitions into the key energy types. The standard phosphor changes about 21% of the UV into visible light, the remaining 39% of the 60% UV being converted into IR.

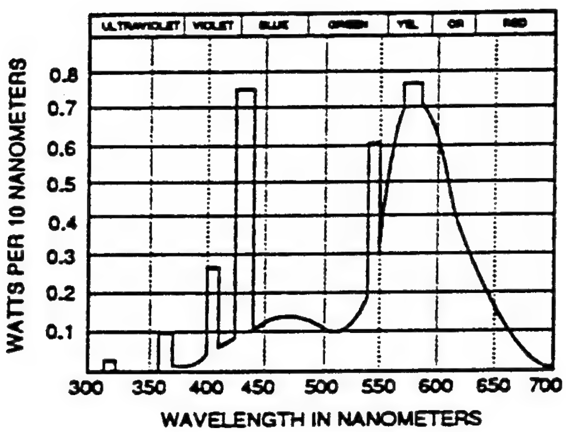
The total 23% of the energy conversion into visible light for a 40 watt lamp turns out to be approximately twice the percentage for a 300 watt incandescent lamp, which changes only 11% of the input energy into visible light. The production of 36% IR by the fluorescent lamp compares with the 69% of a 300 watt incandescent lamp.



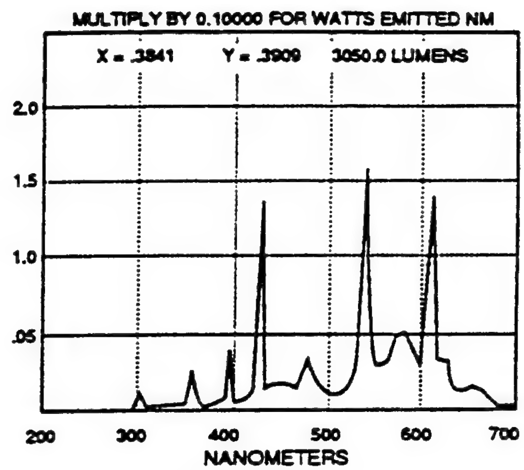
(a) Eye Sensitivity Curve.



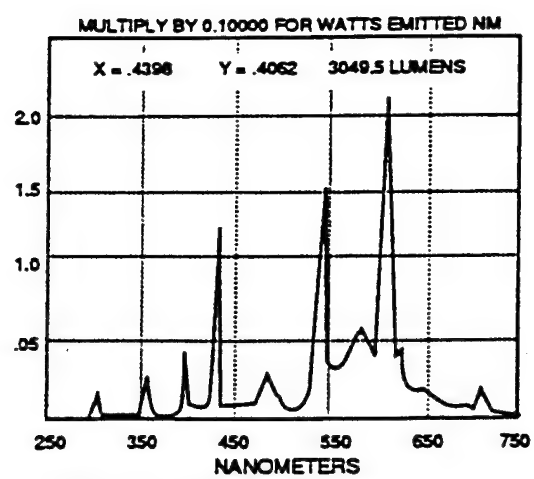
(b) Cool White F40CW



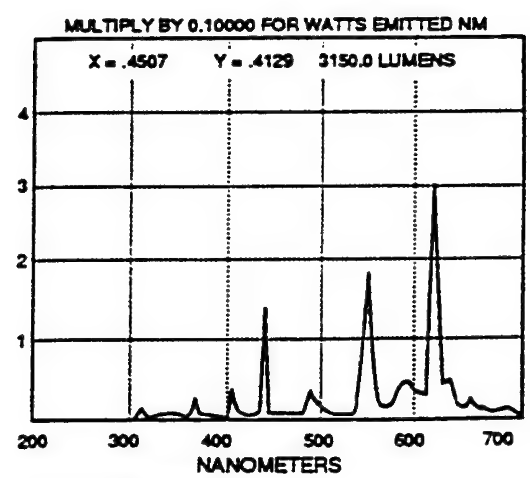
(c) Warm White F40WW



(d) Lite White Deluxe (LWX)



(e) Warm Lite Deluxe (WLX)



(f) Royal White 3K

Figure 28. Spectral Output of Several Types of Fluorescent Lamps

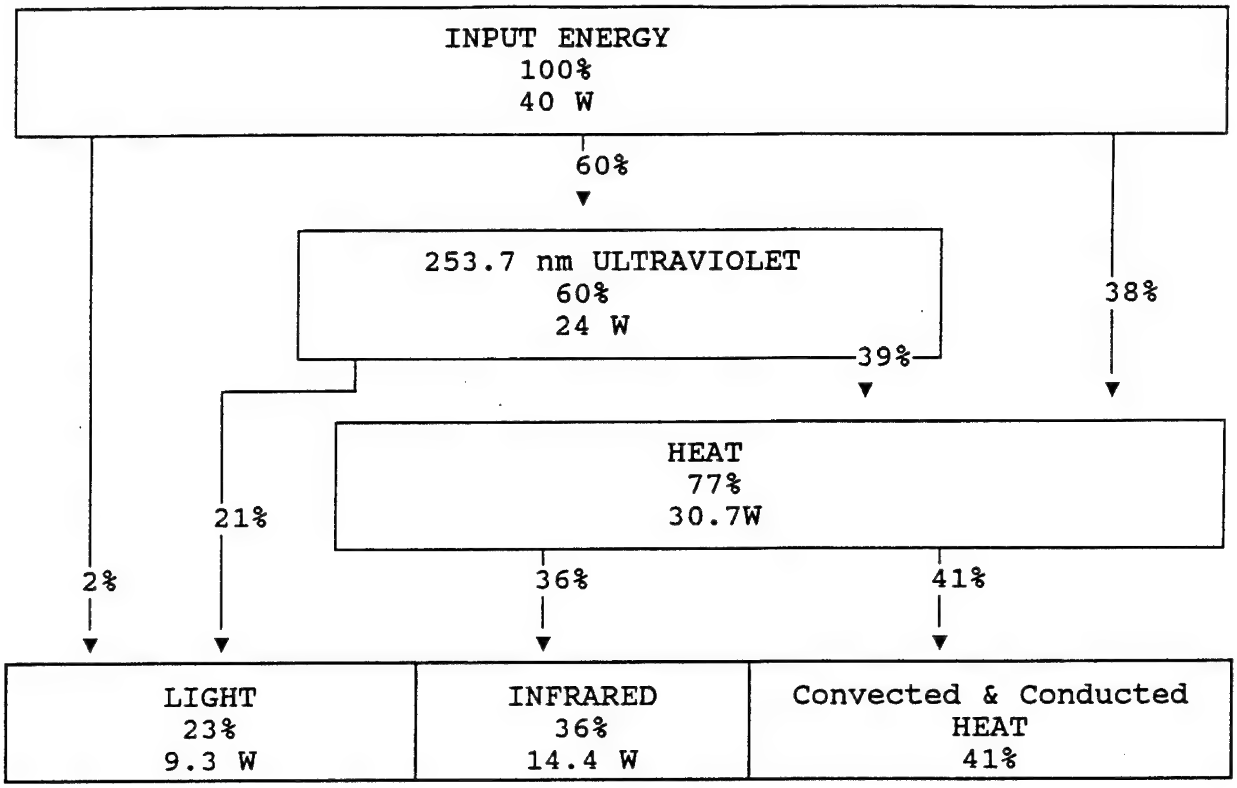


Figure 29. Energy Distribution of a typical 40W Cool White Fluorescent Lamp.

Besides the spectral continuum that a fluorescent lamp emits, the narrow bands of energy given off by the mercury itself are compared relative to each other in Figure 10. Of particular note are the peaks at 185 nm and 253.7 nm, the spectral region exploited by some, if not all UV fire detectors.

As low pressure near-equivalents of the HID family of lamps, the operational characteristics of fluorescent lamps likewise are similar. Their internal pressure is of the order of 1 to 3 torr, having mercury as the primary source for UV excitation of the phosphor coatings, but having a fill gas to facilitate the starting of the arc and maintain its steady state once established. The fill gas can be argon or neon, or sometimes xenon. Energy-saving lamps have a krypton gas fill.

In current use there are three different ways to start a lamp, but, in contradistinction to HID lamps, having very short start times. The three different methods, which result in three different types of ballast, are:

(1) <u>preheat:</u> where the cathode filament, which serves as a thermionic emitter, is heated upon turn-on, and provides the electrons for striking the arc at the appropriate induced voltage. The starting time is several seconds,

not minutes. This, however, is an old way.

(2) instant start: where a high voltage of the order 400 to 1000 volts is used to strike the arc quickly, the arc current serving to provide the heat to facilitate evaporation of the emission material. The start time is immediate upon turn-on. The ballasts used, however, are noisy during operation.

(3) rapid start: where the advantages of preheat and instant start are combined by keeping the cathodes heated during operation, and requiring a lower voltage. The start time is almost immediate, but with quiet operation, cheaper to operate and other advantages. It is the method in common use today.

In all cases, if a lamp goes off, the restrike time corresponds to the start time.

1. The Flicker and Stroboscopic Effect

A characteristic common to both the HID and fluorescent lamps is their capability to flicker as the result of their AC mode of operation. Even though the flicker of the light may not be seen visually, its effect on rotating or oscillating objects may result in seeing a stroboscopic effect, where no motion, or slow motion is seen while the opposite is true.

Since, in AC operation, the voltage goes to zero twice every cycle, there is the basic flicker that occurs 120 times a second when operated at 60 Hz. Another consideration is that every phosphor has a characteristic delay time which can have an impact on the light emission frequency. In short, operational factors of this kind are examples of temporal behavior which can be similar to flame flicker of a fire. As such, they may false alarm a fire detector which uses flame flicker as a fire specificity discriminant.

Table 9 summarizes the percent flicker for the HID lamps with different ballasts, and Table 10 gives the percent flicker for the six different "white" fluorescent lamps.

2. Color Changes

Besides the color changes noted for HID lamps during warmup, and fluorescent lamps during normal operation, for HID lamps, where manual or automatic dimming control is used to either change brightness or conserve energy, one of the side effects is modification of color. The practice of automatic dimming for energy conservation is becoming more widespread.

Table 9

Percent Flicker of Different HID Lamps with Different Ballasts

Lamp Type	Watts	Ballast Type	% Flicker (± 3%)	Flicker Index (± 10%)
Mercury	250	Reactor	88	.30
Mercury DX	400	Reactor	73	.25
Mercury	250	Lead-lag	25	.06
Mercury	400	Lead-lag	20	.05
Mercury	400	Regulator-Reactor	34	.1
Metal Halide (Na, Sc)	400	Reactor	38	.11
Metal Halide (Na, Sc)	1000	Reactor	34	.10
Metal Halide (Na, In, Tl)	1500	Reactor	28	.08
High Pressure Sodium	250	Reactor	95+	.29
High Pressure Sodium	400	Reactor	95+	.29
High Pressure Sodium	1000	Reactor	95+	.29
High Pressure Sodium	250	Lead-lag	50	.16

Table 10

Percent Flicker of Six Different White Fluorescent Lamps

	Single Lamp		2-Lamp Lead-Lag Instant Start		2-Lamp Lead-Lag Preheat Switch Start	
	Flicker Index	% Flicker	Flicker Index	% Flicker	Flicker Index	% Flicker
Cool white	.079	34	.071	26	.056	16
Deluxe cool white	.078	34	.075	27	.046	14
Warm white	.048	20	.044	16	.029	10
Deluxe warm white	.049	20	.043	16	.030	10
Daylight	.119	50	.107	41	.075	24
White	.058	25	.054	20	.042	12

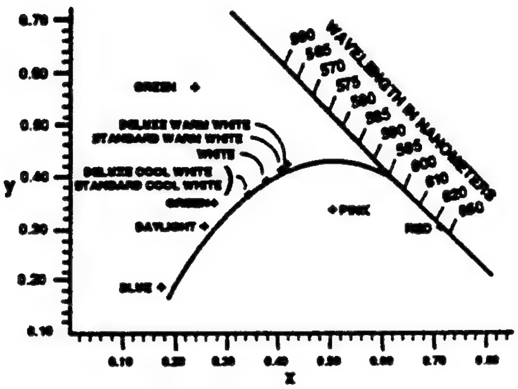
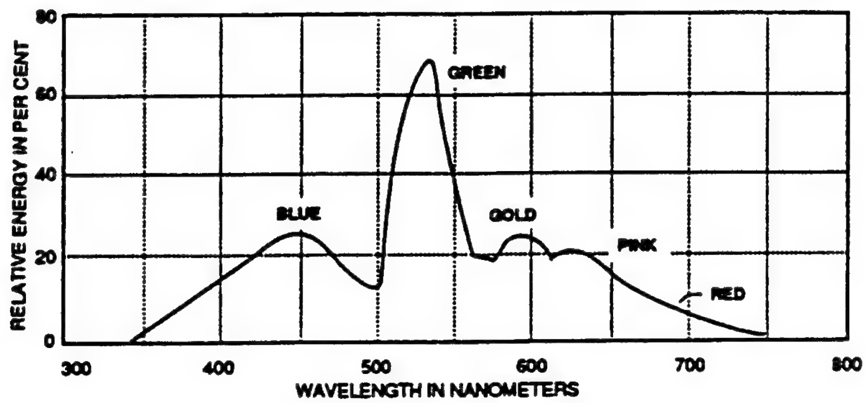
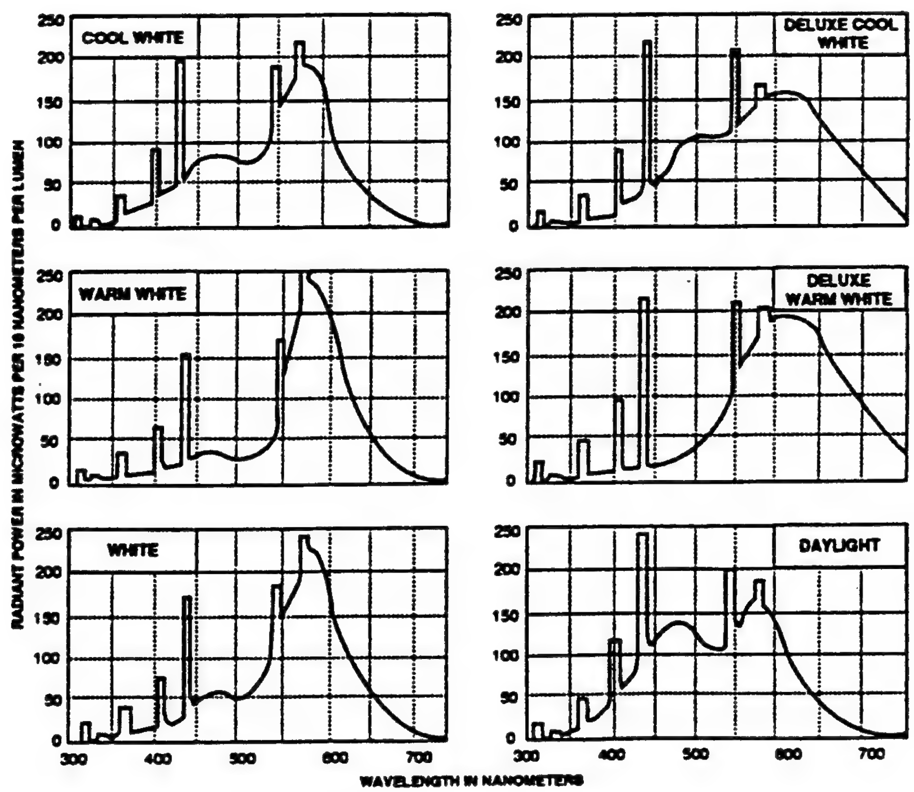


Figure 30. (Left) CIE Chromaticity Diagram Showing Some White and Colored Fluorescent Lamps in Relation to the Blackbody Curve.

(Below) Spectral Power Curves of Light from Typical Fluorescent Lamps.





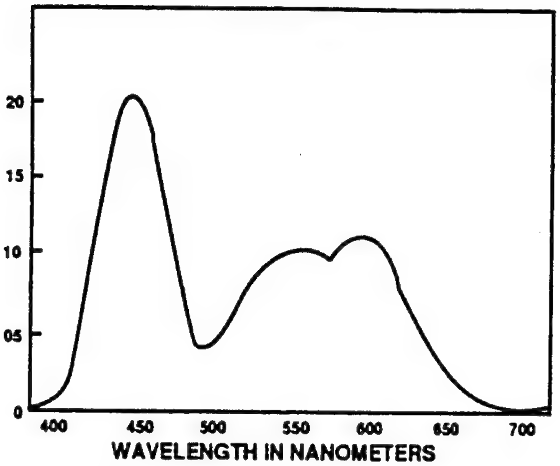
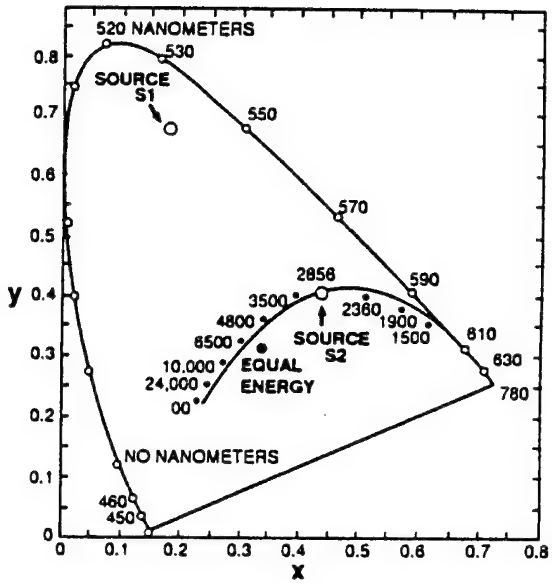


Figure 31. Spectral Tristimulus Values for Equal Spectral Power Source.

Figure 32. Locus of Spectrum Colors Plotted on 1931 CIE Chromaticity Diagram Showing Method of Obtaining Dominant Wavelength and Purity for Different Samples Under Different Light Sources.



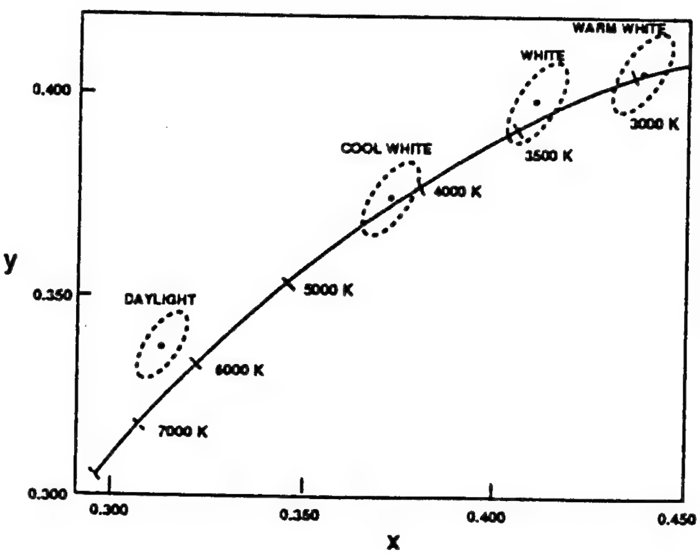


Figure 33. ANSI Colorimetric Standards for Color of Fluorescent Lamps. For Each Class of Lamp the Chromaticity Must Lie within the Elliptical Area Shown.

Table 11

Fluorescent Lamp Powers and Light Outputs

1) Energy Saving Fluorescent Lamps:

Approx. lamp watts:	25	35	95	60
Bulb:	T-12	T-12	T-12	T-12
Nominal length (inches)	36	48	96	96
Lumens:				
Cool White:	2000	2770	8300	5500
Deluxe cool white:		1925	6000	4000
Warm White:	2050	2821	8500	5700
Deluxe warm white:		1925	5720	3870
White:		2820	8300	5600
Daylight:		2300	--	4800

2) Typical Hot-Cathode Fluorescent Lamps (Rapid Starting)

	Circline	Lightly Loaded		Medium Loaded		Highly Loaded	
Approx. lamp watts:	22.5	32.4	41	87	113	215	215
Bulb:	T-9	T-12	T-12	T-12	T-12	T-12	PG
Nominal length (inches)		36	48	72	96	96	96
Lumens:							
Cool White:	1065	2210	3150	6650	9150	15,250	
Deluxe cool white:	875	1555	2200	4550	6533	10,750	
Warm White:	1065	2235	3175	6500	9200	14,650	
Deluxe warm white:	800	1505	2165	--	6475	15,000	
White:	1100	2255	3185	6475	9200	12,650	
Daylight:	906	1900	2615	5600	7800	--	
Factors to Calculate Luminance (cd/m^2):	8.4	3.58	2.65	1.7	1.24	1.24	

3) Typical Hot-Cathode Fluorescent Lamps (Preheat Starting):

Approx. lamp watts:	25.5	30.5	40	90
Bulb:	T-12	T-8	T-12	T-12 or T-17
Nominal length (in.)	33	36	48	60
Lumens:				
Cool White:	1915	2200	3150	6400
Deluxe cool white:	--	1555	2200	--
Warm White:	1935	2235	3175	6350
Deluxe warm white:	--	1505	2165	5710
White:	1925	2255	3185	6350
Daylight:	1635	1900	2615	5525
Factors to Calculate Luminance (cd/m^2):	3.93	5.4	2.65	2.1,1.5

4) Typical Hot-Cathodes Fluorescent Lamps (Instant Starting):

Approx. lamp watts:	30	39	48	50.5	57	75
Bulb:	T-12	T-12	T-12	T-12	T-12	T-12
Nominal length	36	48	60	64	72	96
Lumens:						
Cool White:	2000	3000	3585	3865	4650	6300
Deluxe cool white:	--	2065	--	--	3175	4465
Warm White:	2050	3000	--	3950	4675	6500
Deluxe warm white:	--	2050	--	--	3200	4365
White:	--	3000	--	--	4700	6400
Daylight:	1715	2500	3135	3250	3850	5425
Factors to Calculate Luminance (cd/m^2):	3.58	2.65	2.1	1.95	1.7	1.24

5) Typical Cold Cathode Instant Starting Fluorescent Lamp:

Manufacturer's No.:		48T8			72T8			96T8	
Lamp Watts:									
Low Power:	26	30	--	34	40	--	42	49	--
High Power:	28	33	40	37	43	52	46	54	65
Bulb:		T-8			T-8			T-8	
Lamp Length (inches)		45			69			93	
Lumens:									
Warm White:	1100	1300	1600	1700	2000	2350	2300	2700	3400
White 3500°K:	1050	1250	1550	1650	1900	2300	2250	2650	3300
White 4500°K:	1000	1200	1500	1600	1850	2200	2200	2600	3200
Daylight:	950	1150	1450	1550	1800	2150	2150	2550	3100
Luminance: (cd/m^2)									
Warm White:	4040	4800	5860	4350	5140	6100	4490	5240	6610
White 3500°K:	3940	4590	5690	4250	5040	5930	4385	5140	6440
White 4500°K:	3770	4385	5480	4145	4930	5650	4280	5070	5820
Daylight:	3730	4210	5210	4080	4830	5480	4210	4970	5650

E. Electroluminescent Lamps

Electroluminescent lamp strips have become very common in use for lights on military aircraft. Strips up to 4 inches wide and up to 5 feet long are placed on the sides of the fuselage, the vertical fin, and on the top and bottom surfaces of the wing tips. Modern fighter aircraft may use upwards of 0.45 square meters (4.5 square feet) of green electroluminescent lamps for this purpose. The luminance is continuously controlled from 0 to 70 candelas per square meter (7 candelas per square foot).

For in-flight refueling, tanker airplanes are equipped with a variety of incandescent flood lights and signal lights supplemented with electroluminescent strip lights, enabling the pilot of the

plane being refueled to maintain the proper location. The average luminance of electroluminescent lamps is:

1) green color at 120 volts, 60 Hertz: $27 cd/m^2$
2) green color at 600 volts, 400 Hertz: $38 cd/m^2$

F. Incandescent Lamps

The one component that is common to all incandescent lamps is the filament. Its resistance is driven by voltage and current into an incandescent condition, whereby its temperature is raised to the point where it emits visible light. As such, it is a "black body," which emits heat and light in accordance with the Stefan-Boltzmann law for radiance from a hot body. Strictly speaking, it is a "gray body" if the filament is tungsten, which does not have the emissivity of 1 of a black body, but rather around 0.3 at its high operating temperature. The percentage spectral energy distribution is the same at the temperature whether it is a "black" or "gray" body, but the radiance at each wavelength is proportionately less for a gray body relative to a black body.

Secondary to the filament as the key element in an incandescent lamp is the enclosing bulb, which can be of any shape and finish. Contingent upon the operating temperature, the bulb material and thickness used, and any other special application requirements, will be dictated accordingly. Soft glass is generally used. Hard glass is used for some lamps to withstand higher bulb temperatures and for added protection against bulb breakage due to moisture.

Passing electric current through the filament, and against the filament resistance, consumes electrical power which heats the filament to incandescence. This conversion step of electrical energy to electromagnetic radiation energy, and more specifically to visible light energy, has a certain efficiency which depends on certain parameters. The term used for every lamp is its "efficacy," which is the ratio of its light output in lumens relative to the power input in watts. Edison's first successful lamp, which had a carbon filament, operated at an "efficacy" of only 1.4 lumens per watt.

Efficacies have gone through a series of improvements through the years. Through new filament materials and designs, an efficacy of 10 lumens per watt was reached in 1911 with the introduction of the drawn tungsten wire filament. In 1913 the introduction of gas filled lamps improved the efficacy to 14 lumens per watt. Efficacies of 23 lumens per watt are commonplace in larger commercial type incandescent lamps today. Projection lamps have efficacies up to 33 lumens per watt, and photographic lamps reach 36 lumens per watt.

Although carbon theoretically could have the highest efficacy

of all, since it has the highest "melting point" of any known element, which is 3823°K (3550°C, 6422°F), at which it sublimes into gas rather than melts, this was its principal limitation. It could not be operated at a high enough temperature to obtain the desired efficacy without rapid evaporation, shortening the lamp life. Osmium and tantalum replaced it partly for awhile, until tungsten replaced it almost completely.
Tungsten wire has great strength and durability, and is the best material because it can be heated to very near its melting point of 3655°K (3382°C, 6120°F) without evaporating rapidly. As the operating temperature is increased, the light output and efficacy are increased.

Theoretically, tungsten should yield an efficacy of 52 lumens per watt at its melting point, but the practical limit is about 36 lumens per watt because of losses within the lamp. To reach this efficacy, the life of the lamp is shortened to only eight or ten hours.

1. Tungsten Halogen Lamps

Tungsten halogen lamps are the brightest of the incandescent family of lamps. Their unique characteristics are applicable in any size lamp, from the smallest to the largest incandescent lamps. One particular feature enables these to have the highest efficacies among incandescent lamps, while operating at the highest temperature, yet having a longer life than lamps without this unique feature. It is the "halogen regenerative cycle" that makes this possible.

Tungsten halogen lamps were originally called "iodine quartz lamps" since iodine was the original halogen used inside a tungsten filament lamp with a quartz tube bulb. Since bromine, another halogen element, came to be used in place of iodine in some lamps, the broader designation of tungsten halogen lamps was adopted.

The halogen regenerative cycle works quite effectively. In a standard incandescent lamp, tungsten particles evaporate from the hot filament, and are carried by convection currents to the relatively cool bulb wall, with time building up a black deposit which blocks the light output. However, if iodine is inside the bulb, as the bulb temperature rises, the iodine vaporizes. The tungsten particles and iodine vapor combine to form tungsten iodide. Since the bulb wall temperature must exceed 250°C (523°K, 482°F) to maintain effective operation of the iodine-halogen cycle, a small diameter quartz tube is used as the bulb. Quartz has a melting point of 1650°C (1923°K, 3002°F) which makes it suitable for the extreme heat from high wattage filaments, as well as meeting the temperature requirements of the halogen cycle.

Operation at bulb wall temperatures of 250°C to 1200°C is

readily achieved in small diameter tubular quartz lamps. When tungsten iodide forms in the vicinity of the hot bulb wall, convection currents carry the iodide back to the filament where the temperature is over 2500°C (2773°K, 4532°F). The high temperature breaks down the iodide, tungsten redeposits on the filament, and the free iodine vapor recirculates to continue the regenerative cycle.

This cycle keeps the bulb wall clean and results in a much higher lumen maintenance than obtained with a conventional incandescent lamp. The lamp life would be much longer if the tungsten redeposited evenly on the filament. However, since it does not, it ultimately develops a thinner section and fails the same as a conventional incandescent lamp.

For certain types of tungsten halogen lamps, especially for photographic and reprographic applications, bromine is used instead of iodine. Bromine enables the halogen regenerative cycle to operate at a minimum bulb wall temperature of 200°C (473°K, 392°F), reaching an operating temperature sooner than with iodine. Also, since bromine is relatively colorless, it increases light output by 3% to 5%. Iodine, however, will continue to be used in most standard tungsten halogen lamps.

The spectral energy distribution of tungsten halogen lamps and standard incandescent lamps is similar as shown below.

<u>Approximate Spectral Energy Distribution of Incandescent Lamps</u>

Visible Light	10-12%
Infrared	70%
Ultraviolet	0.2%
Conduction-Convection	19%

Iodine vapor absorbs slightly in the green band, causing a tungsten-iodine incandescent lamp to have a very slight purplish tinge. Since red and blue light as primary colors mix to produce purple light, the effect is as expected. It is noticed for a few seconds after the lamp is turned on, and also while the iodine is condensing in the lamp after it is turned off. When bromine is used instead, a whiter light is produced with no tendency to appear purplish.

2. Incandescent Lamps and Blackbody Radiation

The one characteristic that all incandescent lamps have in common is their relationship to "blackbody" radiation. Where HID lamps produce light by means of high voltage excitation of gases and fluorescent lamps by the UV excitation of luminescence from phosphors, the incandescent lamps produce it by making the filament operate at very high temperatures.

It is this fact that introduces the particular wavelength

dependence of the emissive properties of a filament on its light output. Every material has its own characteristic emission as a function of temperature.

No known radiator, however, has the same emissive power as a blackbody. The ratio of the output of a body at any wavelength to that of a blackbody at the same temperature and the same wavelength is known as the spectral emissivity, $\epsilon(\lambda)$, of the radiator. For a true blackbody, this value would be 1 across all wavelengths.

If the value of the spectral emissivity were to be less than 1, but be constant across all wavelengths, this would define the radiator as a "graybody". However, there is no known radiator that has a constant spectral emissivity for all visible, infrared and ultraviolet wavelengths. A carbon filament comes closest, having a very nearly uniform emissivity in the visible region, making it nearly a "graybody".

For all other materials, however, the emissivity varies with wavelength, and are designated "selective radiators". Tungsten is such a material.

Figure 34 shows the radiation curve for a blackbody, a graybody and tungsten as a selective radiator, all operating at 3000°K. Of particular note are: (1) the radiant power at 4.3μm, and (2) the same as far as the curve goes into the ultraviolet. Being a log-log plot, there is no zero, implying that both wings of the curves continue on to lower radiant powers and other wavelengths. Figure 35 shows a family of blackbody curves for the temperatures from 200° to 10,000°K.

A blackbody curve near 2700°K comes close to representing the radiation from burning propane at 4.3μm, which in turn is a near equivalent to the same wavelength of burning JP-4 fuel. Figures 36 and 37 show the blackbody radiation curves for a temperature at 2700°K, extending into the ultraviolet range of interest as well as the infrared. Table 12 shows the tabulated data for these curves.

It was established in this program that the Air Force requirement that OFDs be capable to detect a 2' x 2' JP-4 pan fire at 100 feet in 5 seconds corresponds to an irradiance in the UV of about 1.4×10^{-4} to 3.89×10^{-5} μW/cm^2 (185 nm - 250 nm band), and in the IR of about 25.9 to 15 μW/cm^2(at 4.37 μm).

Review of Table 12 shows that the irradiance from the filament of an incandescent lamp from 180 to 220nm in the ultraviolet is capable of exceeding the corresponding value for burning JP-4 fuel. Similarly, the value at 4.3μm in the infrared is higher than that obtained from the JP-4 fuel burns.

a. 300 Watt Workshop Quartz Tungsten Halogen Lamp

It was found in the laboratory tests that this lamp was capable of triggering all the OFDs into false alarm. At a distance of 10 feet, with its fixture window removed, and its radiation chopped at a rate of 10 Hz, all detectors used in the tests (eight commercial units) were triggered into false alarm.

Upon analysis it is evident that this was to be expected. Being a slim "Quartzline" lamp, mounted in a semicylindrical reflective fixture, it is commonly used in workshops for added high intensity lighting. It is sometimes used for this purpose in hangars such as flow-throughs.

Bearing in mind it is a small tubular quartz lamp with a hot tungsten filament operating in a halogen atmosphere, it has all the radiant properties of a "selective radiator," with appreciable UV and IR emission and transmission. The analysis above for the 2700° K incandescent lamp is to be paralleled for this lamp, but operating at still higher temperature at about 3000° K. Figure 34 shows its radiation curve.

Comparing exitances at the two temperatures with the JP-4 fuel burn higher exitances, the results are as follows:

	Source	Exitance at 200 nm ($\mu W/cm^2$)	Exitance at 4.37 μm ($\mu W/cm^2$)
(1)	JP-4 Fuel Burn at 100 ft	1.40 E -4	2.59 E 1
(2)	Incandescent Lamp at 2700°K	3.14 E 2	9.84 E 6
(3)	300 W Quartz Tungsten Halogen Lamp at 3000°K	4.50 E 3	1.18 E 7

As is seen, the exitances of the two incandescent sources is much higher than that of the JP-4 fuel burns. the quartz tungsten halogen lamp is considerable greater, and shows why it has the capability to trigger a false alarm in optical fire detectors.

Interestingly enough, the soft white and crystal clear 150 watt incandescent lamps, which operate at a temperature of about 2872°K, likewise have exitances that exceed the JP-4 values:

	Exitance at 200 nm ($\mu W/cm^2$)	Exitance at 4.37 μm ($\mu W/cm^2$)
JP-4 Burn	1.40 E -4	2.59 E 1
Soft White Incandescent Lamp	1.33 E -1	6.68 E 3
Crystal Clear Incandescent Lamp	1.58 E -1	8.27 E 3

These also have been studied in the laboratory and there is indication that these, in combination with the 300 watt quartz tungsten halogen lamp could be used to test OFDs.

Since the bulb for lower wattage lamps attenuates these spectral irradiances considerably, which are further attenuated by the atmosphere and distance, they are less a false alarm threat than high wattage lamps. The tungsten halogen lamps with either quartz, fused silica or borosilicate glass bulbs, however, have higher transmittances in these regions, as well as producing higher radiance at the filament than other incandescent lamps. As is apparent, they present a serious problem in endeavoring to establish immunity of fire detectors against them.

There are so many varieties of incandescent lamps, that, as GE rightfully claims, "GE has an energy-efficient lamp to fit nearly every lighting application". The major part of their catalogue is for incandescent lamps, of which there are hundreds of different types.

To obtain an overall sense of incandescent lamps regarding their full range of filament operating temperatures, bulb temperatures, and their light output, the following tables and figures provide the information.

Table 13 gives the filament temperatures and their associated light output characteristics for standard 120 volt incandescent lamps for power values ranging from 6 watts to 1500 watts. The maximum bare-bulb temperatures for these are given in Table 14. Figure 38 gives the relative spectral energy output in the visible region from tungsten filaments of equal wattage, but across the whole spectrum of absolute operating temperatures. To the extent that it has been summarized above, what comes through the bulb will be determined by the spectral transmittance properties of the bulb.

Table 12

Blackbody Spectral Radiant Exitance
Temperature = 2700°K
Peak Wavelength = 1.07μm
Emissivity = 1.0

Wavelength	Spectral Radiant Exitance	Wavelength	Spectral Radiant Exitance
μm	$\mu W/cm^2$-μm	μm	$\mu W/cm^2$-μm
Ultraviolet		Visible	
0.180	2.75×10^1	0.380	3.84×10^6
0.200	3.14×10^2	0.400	5.98×10^6
0.220	2.19×10^3	0.420	8.84×10^6
0.240	1.07×10^4	0.440	1.25×10^7
0.260	3.95×10^4	0.460	1.69×10^7
0.280	1.80×10^5	0.480	2.21×10^7
0.300	2.97×10^5	0.500	2.82×10^7
0.320	6.53×10^5	0.520	3.49×10^7
0.340	1.28×10^6	0.540	4.22×10^7
0.360	2.31×10^6	0.560	5.00×10^7
Infrared		0.580	5.83×10^7
0.800	1.46×10^8	0.600	6.69×10^7
0.900	1.70×10^8	0.620	7.56×10^7
1.00	1.82×10^8	0.640	8.44×10^7
2.00	8.75×10^7	0.660	9.31×10^7
3.00	3.14×10^7	0.680	1.02×10^8
4.00	1.31×10^7	0.700	1.10×10^8
4.30	1.04×10^7	0.720	1.18×10^8
5.00	6.29×10^6	0.740	1.26×10^8
6.00	3.36×10^6	0.760	1.33×10^8
		0.780	1.40×10^8

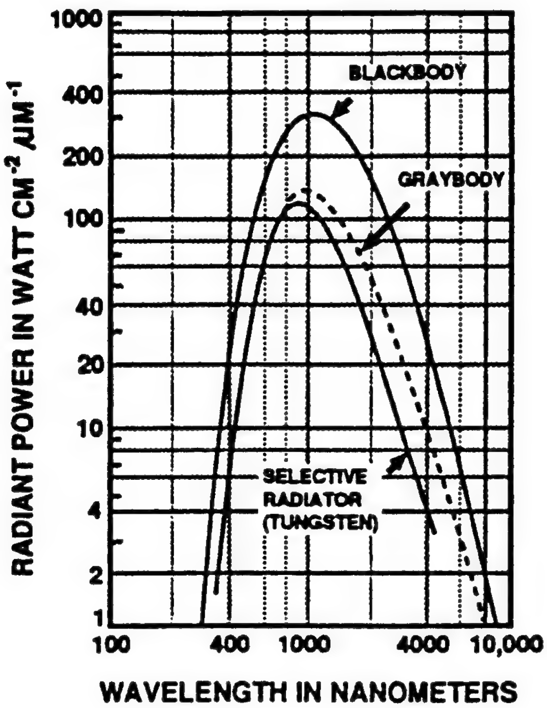


Figure 34. Radiation Curves for Blackbody, Graybody, and Selective Radiators Operating at 3000°K.

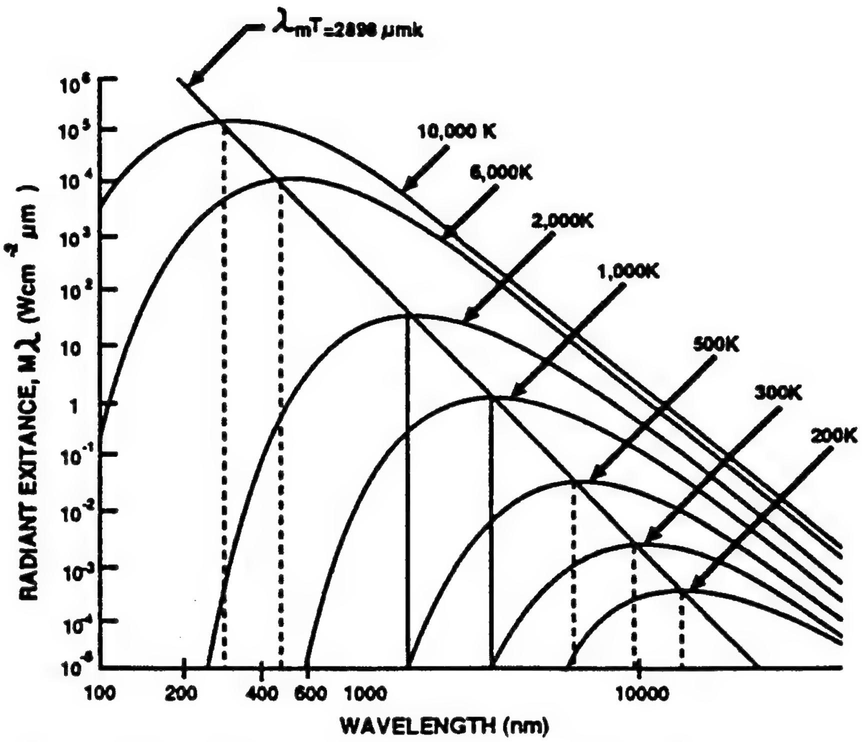


Figure 35. Spectral Radiant Exitance of Blackbodies at Various Temperatures.

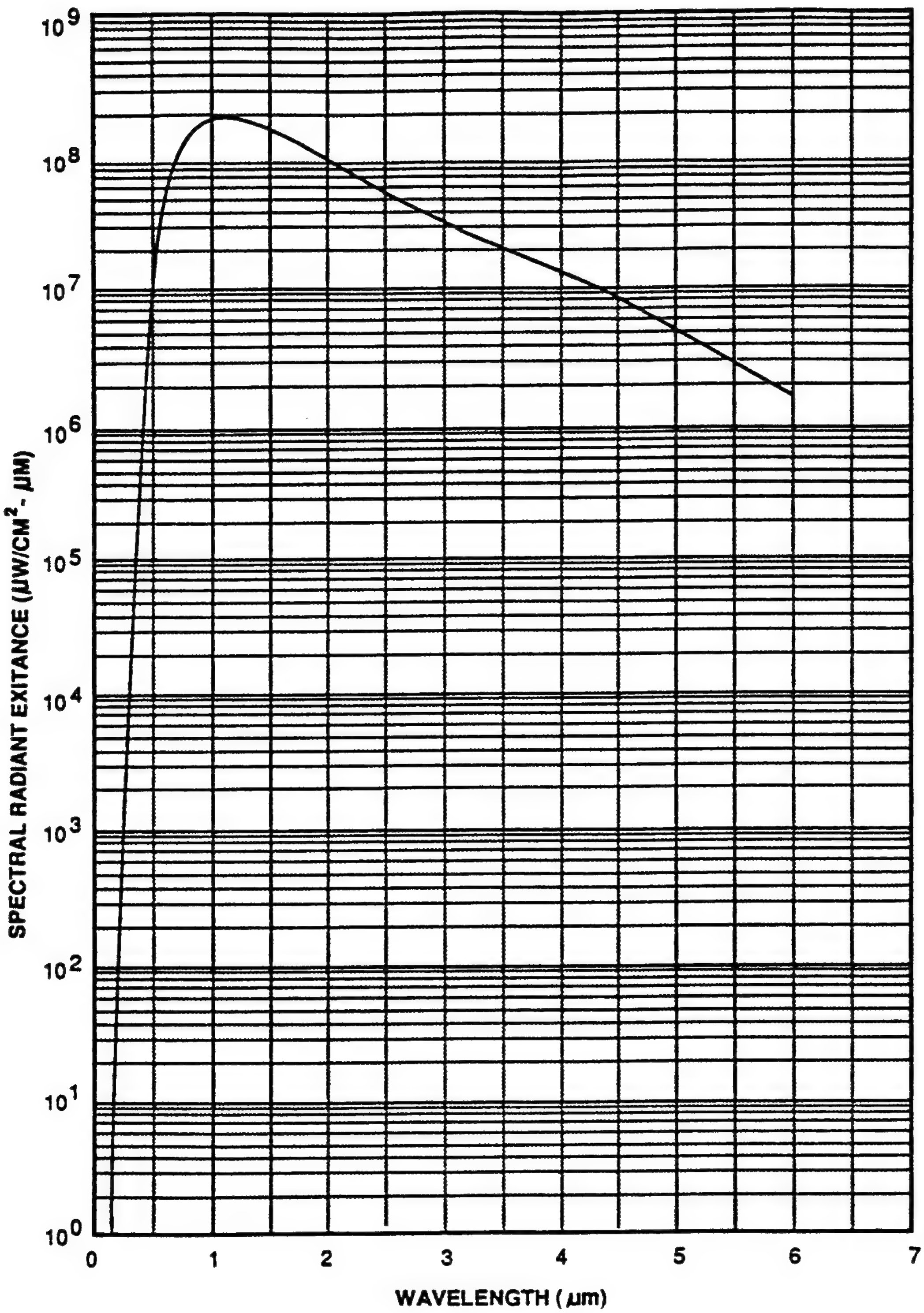


Figure 36. Blackbody Radiation Curve at 2700°K 0-7 μm

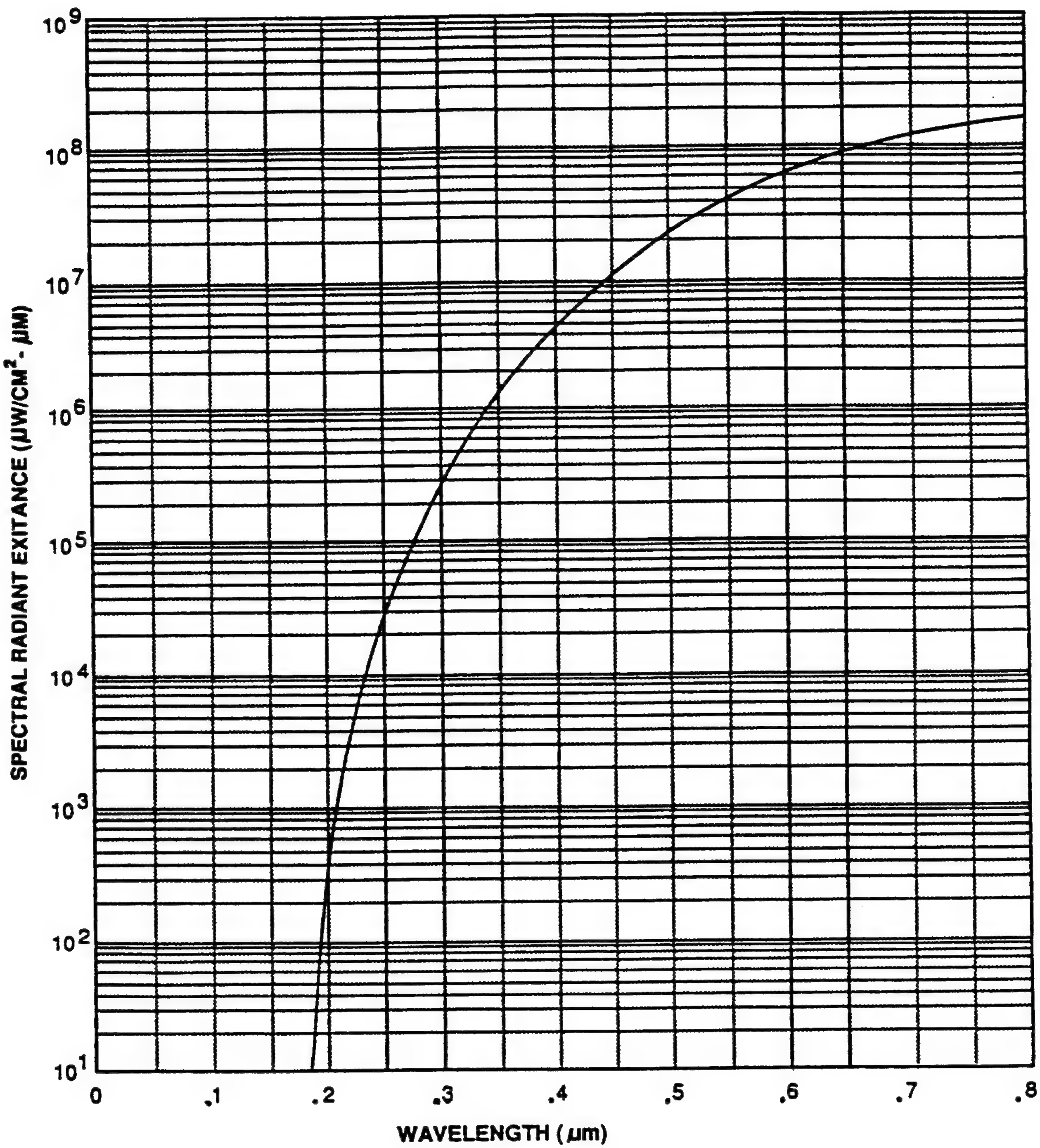


Figure 37. Blackbody Radiation Curve at 2700°K 0.1-0.8 μm

Table 13

Incandescent Lamp Powers and Light Output

Incandescent Lamp Types	Watts	Approx. Lumens	Approximate Filament Temperature $^{\circ}$K
1) General Service Lamps			
Inside Frosted White	100	1740	2905
Inside Frosted White	150	2780	2925
Inside Frosted White	200	4000	2980
2) Rough Service Lamps			
Inside Frosted	100	1250	
Inside Frosted	150	2130	
Inside Frosted	200	3380	
3) Tungsten Halogen Lamps			Approx. Color
(1) Double Ended Types:			Temperature $^{\circ}$K
	200	3460	2900
	500	10,950	3000
	1000	23,400	3000
	1500	35,800	3050
(2) Single Ended Types:			
	75	1400	3000
	100	2500	3000
	150	2900	3000
	250	4850	2950
	500	11,500	3000
	1000	22,400	3050

4) Aircraft Lamps:	Watts	Approximate Maximum Candels cd
(1) Landing (white):	100	110,000
	250	150,000
	450	400,000
	600	600,000
(2) Taxiing (white):	150	32,000
	250	75,000
(3) Navigation (red & green):	25	2.5
	100	11
	150	17

(4) Anticollision:
(red & white)

Minimum	flashing	400 (eff. int.)
Maximum	flashing	>4000 (eff. int.)

5) Wing Inspection (white):

Wing Inspection (white):	50	10,000
	250	90,000

6) Airway Lighting Lamps (Air Force):

		W	cd
(1)	Flush Approach, Threshold, Runway:	100W	80,000
		300W	200,000
		499W	330,000
		200W	200,000 cd
(2)	Threshold, Runway:	503W	11,300 lumens
		200W	16,000 cd
(3)	Approach:	300W	27,000 cd
		500W	48,000 cd
(4)	Medium Intensity Runway Taxiway:	30W	400 lumens
		45W	675 lumens
(5)	Runway Distance Marker:	45W	1,340 cd
(6)	Low Intensity Runway Taxiway:	45W	65,000 cd
(7)	Centerline Runway Taxiway:	45W	710 lumens
		100W	2,080 lumens
(8)	Runway Centerline:	200W	4,500 lumens
(9)	Runway:	200W	4,500 lumens
(10)	Transmissometer	120W	180,000 cd
(11)	Rotating Beam Ceilometer	420W	7,560 lumens
(12)	Flashing Obstruction	500W	9,900 lumens
		620W	9,250 lumens
		700W	11,200 lumens
(13)	Airport Beacon	1200W	27,500 lumens

7) Flashlight Lamps:

	Lamp No.	Watts	Luminous Intensity(cd)
(1)	233	0.63	0.42
(2)	PR2	1.19	0.8
(3)	PR6	0.74	0.45
(4)	406 (flasher)	0.78	--
(5)	PR3	1.79	1.5
(6)	PR7	1.11	0.9
(7)	PR13	2.38	2.2
(8)	PR15	2.41	1.9
(9)	PR12	2.98	3.1
(10)	PR18	3.60	5.5
(11)	PR20	4.32	5.5

8) Projector Lamps:

	ANSI Code	Watts	Approx. Lumens	Approx. Color Temperature °K
(1)	BLC	30	400	2775
(2)	BLX	50	780	2850
	CAR	150	--	3100
	EJL	200	--	3400
	CLS/CLG	300	7600	3200
	FAL	420	11,000	3200
	CZX/DAB	500	12,500	3200
	DYS/DYN/BHC	600	17,000	3200
	DDB	750	19,500	3250
	CTT/DAX	1000	--	3300

9) Electric Heaters and Lamps:

(1) Infrared Energy Sources:
(sheathed resistance radiant heaters 1500-1400nm)

	Watts	Normal Sheath Temp. °C	Heated Length inches
1)	600	700	17
2)	800	790	17
3)	1000	450	70
4)	1000	760	23
5)	1500	730	39
6)	2000	815	46
7)	2500	790	53
8)	3000	790	65
9)	3600	790	77

(2) Tubular Quartz Heat Lamps:

Watts	Lighted Length (inches)
300	4 7/32
375	5
500	5
800	8
1000	10
1200	6
1600	16
2000	9 3/4
2500	25
3800	38
5000	25
5000	50
6000	9 3/4

10) Infrared Lights:

1) Tungsten Filament Lamps (500-4000nm)

Watts	Light Center Length inches
125	5
125	4 7/8
250	5
250	4 7/8
375	5
375	4 7/8
500	5
1000	3 1/4

11) Blackbody (Visible) at Several Temperatures:

	Approximate Average Luminance cd/m^2
6500°K	3×10^9
4000°K	2.5×10^8
2042°K	6×10^5

12) Sealed Beam Lamp Specifications

RECTANGULAR 142mm × 200mm

-11	6052	Auto Headlamp, Type 2B1[28]	12.8/12.8	65W/55W	—	—	—	150[4]/320[4]	3 Contact Lugs	C-6/C-6	138	—
-12	H6054	Halogen Auto Headlamp, Type 2B1[118][151]	12.8/12.8	65W/35W	—	—	—	150[4]/320[4]	3 Contact Lugs	C-6/C-6	138	5 7/16

PAR 36 BULB 114mm (4½ in) DIAMETER[2]

-13	4546	Hand Lantern	4.7	0.5A	6,300	3	3	100	Screw Terminals	C-2R	70	2¾
-14	4546-1	Hand Lantern	4.7	0.5A	6,300	3	3	100	Slip-on Terminals	C-2R	70	2¾
-15	4547	Hand Lantern	4.75	1.25A	20,000	3	3	100	Screw Terminals	C-2R	70	2¾
-16	4547-4	Hand Lantern[152]	4.75	1.25A	20,000	3	3	100	Screw Terminals	C-2R	70	2¾
-17	4346	Hand Lantern[96]	5.3	0.5A	4,000	4	4	100	Screw Terminals	C-2R	70	2¾
-18	4468	Hand Lantern	5.3	0.5A	7,000	3	3	100	Slip-on Terminals	C-2R	70	2¾
-19	H7556	Halogen Emergency Bldg. Lighting[118]	6.0	6W	400	30	20	50	Screw Terminals	C-6	70	2¾
-20	7672-1	Emergency Bldg. Lighting	6.0	7.2W	350	30	20	50	Slip-on Terminals	C-6	70	2¾
-21	7613	Emergency Bldg. Lighting	6.0	8W	400	30	20	50	Screw Terminals	C-6	70	2¾
-22	7613-1	Emergency Bldg. Lighting	6.0	8W	400	30	20	50	Slip-on Terminals	C-6	70	2¾
-23	H7550	Halogen Hand Lantern[118]	6.0	8W	25,000	3	3	50	Screw Terminals	C-6	70	2¾
-24	H7551	Halogen Emergency Bldg. Lighting[118]	6.0	8W	550	30	20	50	Screw Terminals	C-6	70	2¾
-25	H7552	Halogen Emergency Bldg. Lighting[118]	6.0	10W	650	30	20	50	Screw Terminals	C-6	70	2¾
-26	H7553	Halogen Emergency Bldg. Lighting[118]	6.0	12W	850	30	20	50	Screw Terminals	C-6	70	2¾
-27	H7554	Halogen Emergency Bldg. Lighting[118]	6.0	20W	1,400	30	20	50	Screw Terminals	C-6	70	2¾
-28	4634	Aircraft Navigation[82]	6.0	75W	65,000	11	5	300	Screw Terminals	C-6	70	2¾
-29	4614	Aircraft Navigation[82]	6.0	100W	85,000	11	6	300	Screw Terminals	C-6	70	2¾
-30	4516	Spotlamp	6.2	30W	45,000	9	4	300	Screw Terminals	C-6	70	2¾
-31	4511	Tractor	6.2	30W	2,300	Trapezoidal		300[23]	Screw Terminals	C-6	70	2¾
-32	4042	Emergency Bldg. Lighting	6.4	12W	1,100	45	20	150	Screw Terminals	C-6	70	2¾
-33	4014	Emergency Bldg. Lighting	6.4	18W	1,500	50	25	200	Screw Terminals	C-6	70	2¾
-34	4667	Moped Headlamp[17]	6.4	18W	—	—	—	200	Mogul End Prongs	C-6	79.4	3⅛
-35	4667-1	Moped Headlamp[17]	6.4	18W	—	—	—	200	Slip-on Terminals	C-6	70	2¾
-36	4767	Moped Headlamp[17]	6.4	25W	—	—	—	300	Mogul End Prongs	C-6	79.4	3⅛
-37	4767-1	Moped Headlamp[17]	6.4	25W	—	—	—	300	Slip-on Terminals	C-6	70	2¾
-38	4767-2	Moped Headlamp[17]	6.4	25W	—	—	—	300	Screw Terminals	C-6	70	2¾
-39	4510	Tractor Flood, Emergency Bldg. Lighting	6.4	25W	800	80	20	300	Screw Terminals	C-6	70	2¾
-40	4308	Headlamp, Horse-Drawn Vehicles	6.4/6.4	25W/12W	3,000	24,000/ —	—	300/150	3 Screw Terminals	C-6/C-6	70	2¾
-41	4515	Spotlamp[82]	6.4	30W	55,000	5	5	100	Screw Terminals	C-6	70	2¾
-42	H7555	Halogen Emergency Bldg. Lighting[118]	12.0	8W	550	30	20	50	Screw Terminals	C-6	70	2¾

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Approx. Total Spread to 10% Max. C.P.-Base (Degrees)		Rated Average Lab Life (Hours)	Base	Filament Desig-nation	Max. Overall Length	
						Hortz.	Vert.				mm	in

PAR 36 BULB 114mm (4½ in) DIAMETER[2] (continued)

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Hortz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	mm	in
34-1	H7557	Emergency Bldg. Lighting Halogen-Cycle[118]*	12.0	12W	850	30	20	50	Screw Terminals	C-6	70	2¾
-2	4044	Emergency Bldg. Lighting	12.0	12W	1,100	50	25	150	Screw Terminals	C-6	70	2¾
-3	4044-1	Emergency Bldg. Lighting	12.0	12W	1,100	50	25	150	Slip-on Terminals	C-6	70	2¾
-4	4414	Warning Signal, Emergency Bldg. Lighting, Garden and Security Lighting	12.8	18W	1,500	50	25	300	Screw Terminals	C-6	70	2¾
-5	4414-1	Signal	12.8	18W	1,500	50	25	300	Slip-on Terminals	C-6	70	2¾
-6	4414A	Turn Signal, Warning Signal Yellow Lens	12.8	18W	450	50	25	300	Screw Terminals	C-6	70	2¾
-7	4414R	Turn Signal, Warning Signal Red Lens	12.8	18W	275	50	25	300	Screw Terminals	C-6	70	2¾
-8	7414Y	Signal, Light Yellow Lens	12.8	18W	1,000	50	25	300	Screw Terminals	C-6	70	2¾
-9	4446	Emergency Bldg. Lighting	12.8	25W	400	80	80	300	Screw Terminals	C-6	70	2¾
-10	4776	Moped Headlamp[17]	12.8	25W	—	—	—	300	Screw Terminals	C-6	70	2¾
-11	4405	Spotlamp[82]	12.8	30W	50,000	6	5	100	Screw Terminals	C-6	70	2¾
-12	4405-1	Spotlamp[82]	12.8	30W	50,000	6	5	100	Slip-on Terminals	C-6	70	2¾
-13	4416	Spotlamp, Signal	12.8	30W	35,000	11	4	300	Screw Terminals	C-6	70	2¾
-14	4416-1	Spotlamp, Signal	12.8	30W	35,000	11	4	300	Slip-on Terminals	C-6	70	2¾
-15	4416A	Signal, Yellow Lens Cover	12.8	30W	26,000	11	4	300	Screw Terminals	C-6	70	2¾
-16	4416B	Signal, Outside Blue Coating	12.8	30W	—	11	4	300	Screw Terminals	C-6	70	2¾
-17	4416R	Signal, Red Lens Cover	12.8	30W	4,000	11	4	300	Screw Terminals	C-6	70	2¾
-18	4406	Tractor, Flood[134]	12.8	35W	600	80	30	300[4]	Screw Terminals	C-6	70	2¾
-19	4406-1	Tractor, Flood[134]	12.8	35W	600	80	30	300[4]	Slip-on Terminals	C-6	70	2¾
-20	4409X	Farm Tractor[137]	12.8	35W	600	80	30	300[4]	Screw Terminals	C-6	70	2¾
-21	4410	Backup Lamp, Tractor Flood	12.8	35W	—	80	30	300[4]	Screw Terminals	C-6	70	2¾
-22	4411	Tractor	12.8	35W	3,000	Trapezoidal		300[4]	Screw Terminals	C-6	70	2¾
-23	4411-1	Tractor	12.8	35W	3,000	Trapezoidal		300[4]	Slip-on Terminals	C-6	70	2¾
-24	4422	Tractor	12.8	35W	600	75° Cone		300[4]	Screw Terminals	C-6	70	2¾
-25	4603	Tractor[35][84][143]	12.8	35W	2,800	Trapezoidal		300[4]	Screw Terminals	C-6	70	2¾
-26	4603X	Tractor[142]	12.8	35W	2,800	Trapezoidal		300[4]	Screw Terminals	C-6	70	2¾
-27	4415	Fog[81]	12.8	35W	9,000	40	5	300	Screw Terminals	C-6	70	2¾
-28	4415A	Fog, Yellow Lens[81]	12.8	35W	7,000	40	5	300	Screw Terminals	C-6	70	2¾
-29	7400	Signal, Rotating Beacon	12.8	35W	33,000	12	5	300	Slip-on Terminals	C-6	70	2¾
-30	7400-1	Signal, Rotating Beacon	12.8	35W	33,000	12	5	300	Screw Terminals	C-6	70	2¾
-31	7400R	Signal, Rotating Beacon, Red Lens[108]	12.8	35W	4,900	12	5	300	Slip-on Terminals	C-6	70	2¾
-32	H7600	Halogen Signal, Rotating Beacon[118]*	12.8	37.5W	60,000	9	4½	300	Screw Terminals	C-6	70	2¾
-33	H7601-1	Halogen Signal[118]*	12.8	37.5W	4,300	50	25	300	Slip-on Terminals	C-6	70	2¾
-34	H7616	Halogen Spotlamp[118]*	12.8	37.5W	70,000	7	4	300	Screw Terminals	C-6	70	2¾
-35	H7616-1	Halogen Spotlamp[118]*	12.8	37.5W	70,000	7	4	300	Slip-on Terminals	C-6	70	2¾
-36	4440X	Tractor	12.8/12.8	40W/40W	6,000/4,500	40/33	7/9	320/320[4]	3 Contact Lugs	C-6/C-6	76	3
-37	4440X-1	Tractor	12.8/12.8	40W/40W	6,000/4,500	40/33	7/9	320/320[4]	3 Slip-on Terminals	C-6/C-6	70	2¾
-38	4460X	Tractor	12.8/12.8	40W/40W	6,500/5,000	22/22	10/13	320/320[4]	3 Screw Terminals	C-6/C-6	70	2¾
-39	H7606	Tractor, Flood Halogen-Cycle[118]*	12.8	50W	1,000	80	30	400[4]	Screw Terminals	C-6	70	2¾
-40	H7610	Halogen Tractor[118]*	12.8	50W	5,200	Trapezoidal		400[4]	Screw Terminals	C-6	70	2¾
-41	H7614	Halogen Flood[118]*	12.8	50W	2,000	70	30	100	Screw Terminals	C-6	70	2¾
-42	H7604	Halogen Spotlamp[118]*	12.8	50W	100,000	7	5	100	Screw Terminals	C-6	70	2¾
-43	H7675-1	Halogen Special Service[108][118]*	12.8	50W	15,000	35	7	200[4]	Slip-on Terminals	C-6	70	2¾
-44	4425R	C.I.M. Stop/Tail, Red Lens[108]	12.8/12.8	50W/18W	500/100	—	—	200/200[4]	3 Screw Terminals	C-6	70	2¾
-45	4461	Tractor	12.8	60W	6,000	Trapezoidal		300[4]	Screw Terminals	C-6	70	2¾
-46	4464	Signal, Rotating Beacon	12.8	60W	50,000	12	5	300[4]	Screw Terminals	C-6	70	2¾
-47	4464R	Signal, Rotating Beacon Red Lens[108]	12.8	60W	7,000	12	5	300[4]	Screw Terminals	C-6	70	2¾

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Approx. Total Spread to 10% Max. C.P.-Base (Degrees) Horiz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	Max. Overall Length mm	in

PAR 36 BULB (114mm) 4½ in Diameter[2] (continued)

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Horiz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	mm	in
35-1	4466	Tractor[134]	12.8	60W	1,000	80	30	300[4]	Screw Terminals	C-6	70	2¾
-2	4460X-4	Tractor	12.8/12.8	60W/60W	—	—	—	—	3 Screw Terminals	C-6	70	2¾
-3	4675	Special Service[81][108]	13.0	75W	15,000	40	7	300	Slip-on Terminals	C-6	70	2¾
-4	4509	Aircraft Landing Spotlamp[96]	13.0	100W	110,000	12	6	25	Screw Terminals	C-6	70	2¾
-5	4509X	Marine Spotlamp[82]	13.0	100W	110,000	12	6	25	Screw Terminals	C-6	70	2¾
-6	4519	Marine	13.0	100W	30,000	40	7	25	Screw Terminals	C-6	70	2¾
-7	4595	Aircraft Navigation	13.0	100W	60,000	14	6	300	Screw Terminals	C-6	70	2¾
-8	4700	Spot/Flood	13.0/13.0	100/100W	72,000/30,000	12/17	7/18	25/25	3 Screw Terminals	C-6	70	2¾
-9	4313	Aircraft Landing	13.0	250W	—	—	—	25	Screw Terminals	C-6	70	2¾
-10	04631	Halogen Quartzline®, Aircraft Landing, Wing Inspection[14][118]*	13.0	250W	80,000	13	12	500	Screw Terminals	C-6	70	2¾
-11	04632	Halogen Quartzline®, Aircraft Logo[14][96][118]*	13.0	250W	75,000	14	12	500	Screw Terminals	C-6	70	2¾
-12	4502	Auto Headlamp, Military	28.0	50W	10,000	40	7	400	Screw Terminals	C-6	70	2¾
-13	4505	Aircraft Navigation	28.0	50W	45,000	11	5	400	Screw Terminals	CC-6	70	2¾
-14	4589	Aircraft Cockpit Flood, C.I.M. Flood	28.0	50W	5,000	Trapezoidal		400	Screw Terminals	CC-6	70	2¾
-15	4593	Aircraft In-Air Refueling, Flood	28.0	50W	1,500	80	30	400	Screw Terminals	CC-6	70	2¾
-16	4825R	C.I.M. Stop/Tail, Red Lens[96][108]	28.0/28.0	50W/18W	200/40	—	—	200/200	3 Screw Terminals	C-2V/C-2V	70	2¾
-17	4750	C.I.M. Headlamp	28.0	60W	5,000	36	12	800	Screw Terminals	2C-6	70	2¾
-18	4752	C.I.M. Flood	28.0	60W	2,000	50	25	800	Screw Terminals	2C-6	70	2¾
-19	4591	Aircraft Landing	28.0	100W	90,000	12	6	25	Screw Terminals	CC-6	70	2¾
-20	4594	Aircraft Navigation	28.0	100W	70,000	13	7	300	Screw Terminals	CC-6	70	2¾
-21	4627	Aircraft Flood	28.0	100W	3,000	80	30	300	Screw Terminals	CC-6	70	2¾
-22	4811	Auto Headlamp, Military	28.0/28.0	110W/55W	—	—	—	400/400	3 Contact Lugs	CC-6/CC-6	76	3
-23	4626	Aircraft Taxiing	28.0	150W	25,000	40	9	300	Screw Terminals	CC-6	70	2¾
-24	4587	Aircraft Taxiing[14]	28.0	250W	40,000	40	13	25	Screw Terminals	CC-8	70	2¾
-25	4596	Aircraft Landing[14]	28.0	250W	150,000	11	12	25	Screw Terminals	CC-8	70	2¾
-26	4350	Electric Truck Work Light[15]	36.0	60W	2,100	Trapezoidal		400	Screw Terminals	C-2V	70	2¾
-27	4340	Electric Truck Work Light[15]	48.0	80W	2,500	Trapezoidal		400	Screw Terminals	C-2V	70	2¾

PAR 46 BULB 146mm (5¾ in) DIAMETER[2]

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Horiz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	mm	in
-28	4606	Emergency Lighting	5.7	3.7A	800	80	20	150	Screw Terminals	C-6	95	3¾
-29	4019	Tractor	6.2	30W	1,200	Trapezoidal		300[23]	Screw Terminals	C-6	95	3¾
-30	4013	Tractor, Flood	6.4	25W	800	80	20	300	Screw Terminals	C-6	95	3¾
-31	4535	Spotlamp[82]	6.4	30W	95,000	5½	4	100	Screw Terminals	C-6	95	3¾
-32	4020	Cycle Headlamp	6.4/6.4	30W/30W	—	—	—	300/300	3 Contact Lugs	C-6/C-6	102	4
-33	4031	Auto Headlamp, Military	6.4/6.4	45W/45W	—	—	—	300/500	3 Contact Lugs	C-6/C-6	102	4
-34	4078	C.I.M. Flood	6.4	50W	1,600	—	—	500[23]	2 Contact Lugs	C-6/C-6	102	4
-35	4531	Auto Headlamp, Military	12.5	40W	30,000	20	5	400	Screw Terminals	C-6	95	3¾
-36	4439X	Special Service[96]	12.8	18W	900	60	20	300	2 Contact Lugs	C-6	102	4
-37	4435	Spotlamp[82]	12.8	30W	75,000	5	5	100[4]	Screw Terminals	C-6	95	3¾
-38	4420	Cycle Headlamp[146]	12.8/12.8	30W/30W	—	—	—	300/300	3 Contact Lugs	C-6/C-6	102	4
-39	4412	Fog[81]	12.8	35W	11,000	40	7	300	Screw Terminals	C-6	95	3¾
-40	4412-1	Fog[81]	12.8	35W	11,000	40	7	300	Slip-on Terminals	C-6	95	3¾
-41	4412A	Fog, Yellow[81]	12.8	35W	8,800	40	7	300	Screw Terminals	C-6	95	3¾
-42	4412A-1	Fog, Yellow[81]	12.8	35W	8,800	40	7	300	Slip-on Terminals	C-6	95	3¾
-43	4413	Tractor, Flood[134]	12.8	35W	1,100	80	20	300[4]	Screw Terminals	C-6	95	3¾
-44	4413R	Signal, Red Lens[108]	12.8	35W	200	80	20	300[4]	Screw Terminals	C-6	95	3¾
-45	4419	Tractor[84]	12.8	35W	1,600	Trapezoidal		300[4]	Screw Terminals	C-6	95	3¾
-46	4427	Tractor, Flood[36][107]	12.8	35W	1,200	80	20	300[4]	Screw Terminals	C-6	95	3¾
-47	4436	Signal	12.8	35W	60,000	10	4	300	Screw Terminals	C-6	95	3¾
-48	4436R	Signal, Red Lens[108]	12.8	35W	9,000	10	4	300	Screw Terminals	C-6	95	3¾
-49	H5006	Halogen Auto Headlamp, Low Beam Type 2C1[118]*	12.8/12.8	35W/35W	—	—	—	200/320[4]	3 Contact Lugs	C-6/C-6	102	4
-50	4000	Auto Headlamp, Low Beam Type 2C1[26]*	12.8/12.8	37.5W/60W	—	—	—	200/320[4]	3 Contact Lugs	C-6/C-6	102	4

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Approx. Total Spread to 10% Max. C.P.-Base (Degrees) Hortz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	Max. Overall Length mm	in

PAR 46 BULB 146mm (5¾ in) DIAMETER[2] (continued)

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Hortz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	mm	in
36-1	4040	Truck Headlamp, Low Beam Heavy Duty, Type 2C1[28][14]	12.8/12.8	37.5W/60W	—	—	—	300/500[4]	3 Contact Lugs	C-6/C-6	102	4
-2	H4001	Halogen Auto Headlamp, High Beam Type 1C1[116]•	12.8	37.5W	—	—	—	200[4]	2 Contact Lugs	C-6	102	4
-3	4001	Auto Headlamp, High Beam Type 1C1	12.8	37.5W	—	—	—	300[4]	2 Contact Lugs	C-6	102	4
-5	H7612	Halogen Fog[116]•	12.8	37.5W	15,000	40	7	450	Screw Terminals	C-6	95	3¾
-6	4434A	School Bus Signal, Amber Lens	12.8	40W	1,000	55	25	100	Screw Terminals	C-6	95	3¾
-7	4459	Tractor[84]	12.8/12.8	40W/40W	1,400/1,300	Trapezoidal		320/320[4]	3 Slip-on Terminals	C-6/C-6	84	3 3/16
-8	4431	Auto Headlamp, Military	12.8/12.8	45W/35W	—	—	—	320/320[4]	3 Contact Lugs	C-6/C-6	102	4
-9	H7609	Halogen Tractor Flood[116]•	12.8	50W	2,200	80	20	400[4]	Screw Terminals	C-6	95	3¾
-10	H7619	Halogen Tractor[84][116]•	12.8	50W	6,000	Trapezoidal		400[4]	Screw Terminals	C-6	95	3¾
-11	H7621-1	Halogen Auto/Truck Special Service[108][116]•	12.8	50W	20,000	50	7	200[4]	Slip-On Terminals	C-6	95	3¾
-12	H7635	Halogen Spotlamp[116]•	12.8	50W	160,000	6½	4	100	Screw Terminals	C-6	95	3¾
-13	4467	Cycle Headlamp[14]	12.8/12.8	50W/35W	—	—	—	320/275[4]	3 Contact Lugs	C-6/C-6	102	4
-14	4492	Snowmobile Headlamp[86]	12.8/12.8	60W/60W	21,000/19,000	—	—	300/300	3 Contact Lugs	C-6/C-6	102	4
-15	4478	C.I.M. Flood	13.0	60W	1,600	—	—	800[4]	2 Contact Lugs	2C-6	102	4
-16	4421	Auto/Truck, Special Service[82][108]	13.0	100W	23,000	50	7	300	Slip-on Terminals	C-6	95	3¾
-17	4537	Aircraft Landing[20][83][96]	13.0	100W	200,000	11	6	25	Screw Terminals	C-6	80	3⅛
-18	4537-1	Spotlamp[20][96]	13.0	100W	200,000	11	6	25	Slip-on Terminals	C-6	80	3⅛
-19	4537-2	Spotlamp[20][96]	13.0	100W	200,000	11	6	25	Screw Terminals	C-6	80	3⅛
-20	4537X	Marine Spotlamp[20][82]	13.0	100W	200,000	11	6	25	Screw Terminals	C-6	80	3⅛
-21	4705	Spot/Flood	13.0/13.0	100W/100W	130,000/40,000	—	—	25/25	3 Screw Terminals	C-6/C-6	95	3¾
-22	4522	Aircraft Landing[83]	13.0	250W	290,000	12	10	25[138]	Screw Terminals	C-2[82]	80	3⅛
-23	4633R	School Bus, Signal, Red Lens	14.0	80W	—	—	—	200	Slip-on Terminals	2C-6	95	3¾
-24	4636	Signal	14.0	80W	90,000	9	7½	200	Screw Terminals	2C-6	95	3¾
-25	4636-1	Signal	14.0	80W	90,000	9	7½	200	Slip-On Terminals	2C-6	95	3¾
-26	4635	Aircraft Landing[14]	16.5	450W	325,000	14	15	25	Screw Terminals	C-8	95	3¾
-27	4530	Signal, Flashing[86]	26.0	5.3A	100,000	11	11	50	Screw Terminals	4CC-8	95	3¾
-28	4578	C.I.M. Flood	28.0	60W	1,600	55	30	800	2 Contact Lugs	2C-6	102	4
-29	4880	C.I.M. Headlamp	28.0	60W	6,000	—	—	800	2 Contact Lugs	2C-6	102	4
-30	4579	C.I.M. Headlamp	28.0	80W/60W	24,000/11,000	—	—	400/400	3 Contact Lugs	CC-6/CC-6	102	4
-31	4570	Aircraft Taxiing	28.0	150W	32,000	50	90	300	Screw Terminals	CC-6	95	3¾
-32	4571	Flood, Special Service	28.0	150W	7,000	80	25	300	Screw Terminals	CC-6	95	3¾
-33	4572	Auto Flood, Military	28.0	150W	4,500	55	55	300	Screw Terminals	CC-6	95	3¾
-34	4551	Aircraft Taxiing	28.0	250W	75,000	50	10	25[138]	Screw Terminals	CC-6	95	3¾
-35	4553	Aircraft Landing[83]	28.0	250W	300,000	11	12	25	Screw Terminals	CC-8	80	3⅛
-36	4554	Aircraft Taxiing[14]	28.0	450W	90,000	50	16	25	Screw Terminals	CC-8	80	3⅛
-37	Q4554	Halogen Quartzline®, Aircraft Taxiing[14][116]•	28.0	450W	65,000	50	11	100	Screw Terminals	CC-6	67	2⅝
-38	4580	Aircraft Landing[14][18]	28.0	450W	400,000	13	14	10	Screw Terminals	CC-8	95	3¾
-39	4581	Aircraft Landing[14][20]	28.0	450W	400,000	13	14	10	Screw Terminals	CC-8	80	3⅛
-40	4582	Aircraft/Helicopter Flood[14]	28.0	450W	20,000	50	55	10	Screw Terminals	CC-8	95	3¾
-41	Q4597	Halogen Quartzline®, Aircraft Flood[14][118]	28.0	450W	16,000	60	35	1,000	Screw Terminals	CC-6	84	3 3/16
-42	Q4681	Halogen Quartzline®, Aircraft Landing[14][118]	28.0	450W	310,000	15	9	50	Screw Terminals	CC-6	67	2⅝

PAR 56 BULB 178mm (7 in) DIAMETER[2]

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Hortz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	mm	in
-43	6006	Auto Headlamp[28]	6.1/6.2	50W/40W	—	—	—	300/500	3 Contact Lugs	C-6/C-6	127	5
-44	4545	Marine Searchlight[82]	12.0	100W	225,000	9	5	100	Screw Terminals	C-6	114	4½
-45	4543	Marine Spotlamp	12.5	100W	250,000	9	5	50	Screw Terminals	C-6	114	4½
-46	6014	Auto Headlamp, Type 2D1[28]	12.8/12.8	60W/50W	—	—	—	200/320[4]	3 Contact Lugs	C-6/C-6	127	5
-47	H6024	Halogen Auto Headlamp, Type 2D1[116]•	12.8/12.8	65W/35W	—	—	—	150/320[4]	3 Contact Lugs	C-6/C-6	127	5

Line No.	GE Lamp No.	Primary Application	Design Volts	Design Watts or Amps	Approx. Initial Maximum Beam C.P.	Approx. Total Spread to 10% Max. C.P.-Base (Degrees) Horiz.	Vert.	Rated Average Lab Life (Hours)	Base	Filament Designation	Max. Overall Length mm	in
PAR 56 BULB 178mm (7 in) DIAMETER[2] (continued)												
37-1	6015	Auto/Truck Headlamp, Heavy Duty, Type 2D1[26][46]	12.8/12.8	60W/50W	—	—	—	300/500	3 Contact Lugs	C-6/C-6	127	5
-2	4433A	School Bus Signal, Yellow Lens	14.0/14.0	40W/40W	—	—	—	200/200	3 Contact Lugs	C-6/C-6	127	5
-3	4433R	School Bus Signal Red Lens[10]	14.0/14.0	40W/40W	—	—	—	200/200	3 Contact Lugs	C-6/C-6	127	5
-4	4800	Auto Headlamp, Military	28.0/28.0	50W/40W	—	—	—	400/400	3 Contact Lugs	CC-6/CC-6	127	5
-5	4860	Auto Headlamp, Military	28.0/28.0	80W/60W	—	—	—	400/400	Waterproof Terminals	CC-6/CC-6	127	5
-6	4863	Auto Headlamp, Military[26]	28.0/28.0	80W/80W	—	—	—	400/400	Waterproof Terminals	CC-6/CC-6	127	5
-7	4541	Aircraft Landing[34][53]	28.0	450W	470,000	15	11	25	Screw Terminals	C-13	114	4½
PAR 64 203mm (8 in) DIAMETER[2]												
-8	4552	Aircraft Landing[53]	28.0	250W	500,000	7	8	25[13][38]	Screw Terminals	CC-8	95	3¾
-9	4559	Aircraft Landing[53]	28.0	600W	600,000	11	12	25[13][38]	Screw Terminals	CC-8	95	3¾
-10	Q4559	Halogen Quartzline®, Aircraft Landing[11][18]	28.0	600W	600,000	12	8	100[13][38]	Screw Terminals	CC-6	95	3¾
-11	Q4559X	Halogen Quartzline®, Aircraft Landing[11][18]	28.0	600W	765,000	11	7½	100[13][38]	Screw Terminals	CC-6	95	3¾
-12	Q4629	Halogen Quartzline®, Aircraft Logo Light[11][18]	28.0	600W	20,000	55	35	1000	Screw Terminals	CC-6	122	4 13/16
-13	4557	Aircraft Landing/Taxiing[14]	28.0/28.0	1,000W/ 400W	100,000	540,000/ —	—	25/100[13][38]	3 Screw Terminals	CC-8/C-6	95	3¾
-14	4555	Aircraft Landing[14][15]	115.0	1,000W	600,000	20	11	25[13][38]	Screw Terminals	—	95	3¾

Footnotes

(2) Approximate.

(3) Useful hours.

(4) At 14 volts.

(7) Entire bulb selected for minimum glass imperfections.

(8) Bulb top selected for minimum glass imperfections.

(10) At 5 volts.

(11) **CAUTION: This halogen-cycle bulb could shatter if scratched or damaged. Use appropriate protection when handling, using, or disposing. Use in fixtures designed for the high temperature required for proper operation and that offer protection in case the bulb shatters. Turn power off when changing lamp. Allow lamp to cool before removal. For satisfactory performance: (1) limit seal and outer lead wire temperature to 350°C or lead wire deterioration may occur; (2) maintain a minimum bulb wall temperature of 250°C for operation of the halogen cycle; (3) operate at design volts; (4) if further processing of the leads, such as bending, welding, crimping, etc. is required, care must be taken to assure that the lamp seal area is not strained, cracked, chipped, or otherwise damaged or premature lamp failure may occur.**

(12) Average overall length.

(13) Supported.

(14) This lamp is specially designed for a particular purchaser and may not be suitable for other uses because of its excessive wattage requirements for the bulb size. Consult the nearest GE Lamp Sales Office for application information.

(15) This lamp is specially designed for a particular purchaser and may not be suitable for other uses because of its limited mechanical strength. Consult the nearest GE Lamp Sales Office for application information.

(17) Filament shielded.

(18) Rounded cover.

(20) Slightly rounded cover.

(21) Top of bulb light outside frosted.

(23) At 7 volts.

(26) Lower beam filament shielded.

(32) Designed and rated for operation in supplementary cathode preheat circuits for which specifications are available from the lamp manufacturer.

(33) Connections of major and minor fil. to base are reversed from those for automotive lamps with Double Contact Index bases.

(34) Clear round window in reflector below base terminals.

(35) Outside transparent red coating on reflector. Transparent round window in reflector below base terminals.

(38) Actual life depends upon use and environment. Theoretical design average life is 100,000+ hours.

(42) Actual life depends upon use and environment. Theoretical design average life is 25,000 hours.

(43) Actual life depends upon use and environment. Theoretical design average life is 50,000 hours.

(44) At 6.6 volts.

(45) Threaded base approximately 3/16" diameter by approximately ¼" long.

(52) Light center length measured from open end of base to filament center. Three-part base with inner sleeve approximately 7/32" long, and with outer part of base threaded and knurled.

(53) Side solder within 25° of plane of filament. With lamp horizontal and side solder in uppermost position, the following beam pattern limits are provided on a surface perpendicular to the base axis and located ⅜" from end of bulb: 750 footcandles minimum over a 1/16" diameter circle centered on base axis. While entire beam may not be centered on base axis, it will fall between two parallel vertical lines 3/16" apart which are centered on the base axis.

Table 14

Filament Temperatures and Efficacies of 120 Volt Incandescent Lamps

Lamp Watts	Bulb Size	Approx. Filament Temp. °K	Approx. Color Temp Kelvin	Approx. Initial Lumens	Efficacy Lumens per Watt
6*	S-14	2399	2370	40	6.5
10*	S-14	2422	2450	86	8.0
24*	A-17	2583	2550	235	9.4
40	A-17	2739	2770	460	11.5
60	A-17	2772	2800	890	14.8
100	A-17	2850	2870	1750	17.4
150	A-21	2872	2900	2850	19.2
200	A-23	2899	2930	3940	19.7
300	PS-30	2939	2940	6000	20.0
500	PS-35	2944	2960	10600	21.0
1000	PS-52	3022	3030	23100	23.1
1500	PS-52	3039	3070	33620	22.4

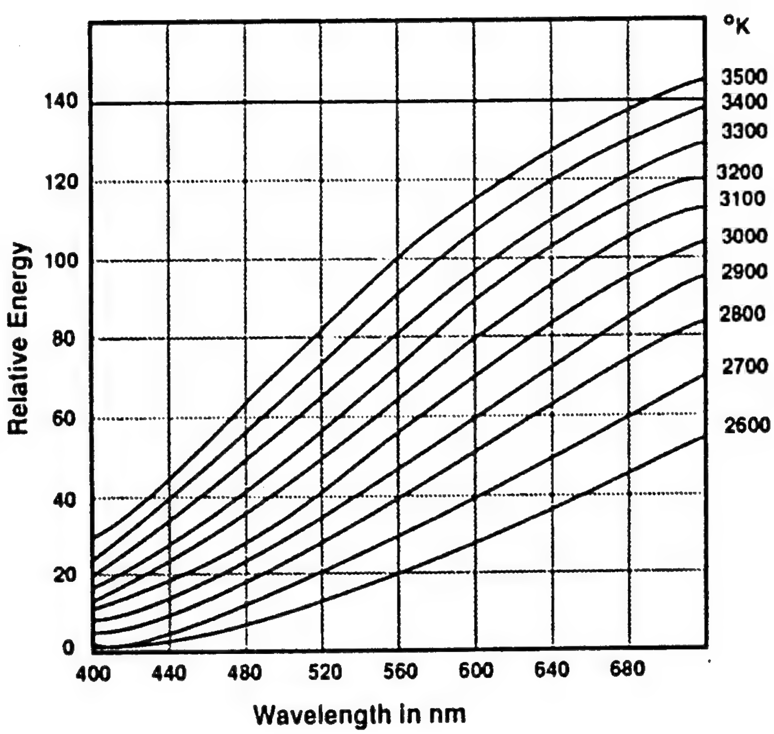


Figure 38. Spectral Power Distribution in the Visible Region from Tungsten Filaments of Equal Wattage but Different Temperatures.

Table 15

Maximum Bare-Bulb Temperatures of Standard Incandescent Lamps*

Watts	Bulb	°Fahr.	°Kelvin
25	A-19	110	316
40	A-19	260	400
60	A-19	255	397
100	A-19	300	422
150	A-23	280	411
200	A-23	345	447
300	PS-30	385	469
500	PS-35	415	486
1000	PS-52	480	522
500	PS-52	510	539

*Bare lamp burning vertically, base up.

G. Electrical Arcs and Discharges

The arcing of power transformers, motors and any other electrical devices produces a spark or sparking in air which has the same spectral effect as lightning. Whatever is in the air locally, as well as whatever materials are involved in the source and grounding of the spark, will determine the spectral content of the spark discharge. Like lightning, the principal emissions are of nitrogen bands; sometimes hydrogen lines, and that of the other materials involved.

Flashlamps spectrally are as described under "Lights" above. The Norman family of flashlamps feature xenon gas-filled flashlamps, which therefore have a spectral output characteristic of xenon lamps. The energy output of the three Norman flashlamps measured at Edwards AFB is as follows:

Norman 200B:	200 watt-seconds
Norman P500:	500 watt-seconds
Norman 2000B:	2000 watt-seconds

Other flashlamps at Edwards AFB have outputs as follows:

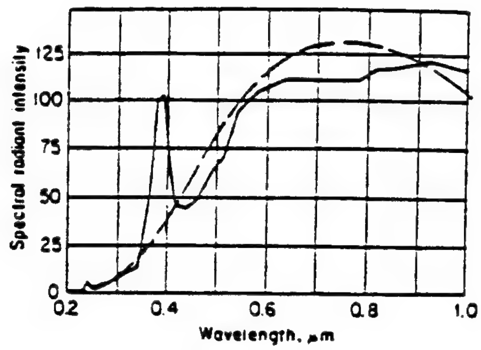
Metz 60CT-4	160 watt-seconds, variable
Vivitar 285HB:	125 watt-seconds

Carbon arcs are of three types: (1) low intensity, (2) high intensity, and (3) flame arcs.

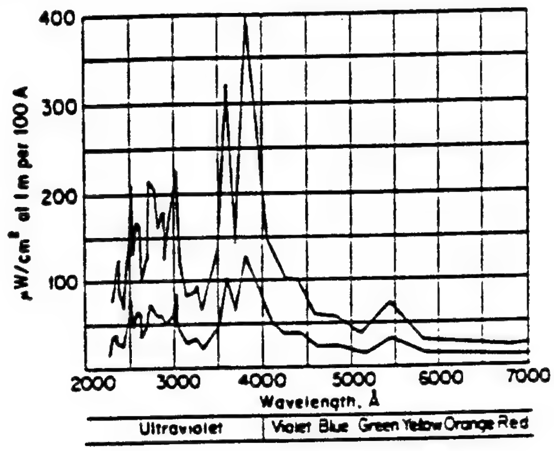
The low intensity arc, when operated at radiation standard conditions, corresponds to a blackbody at 3800°K. The luminance can be varied from 150 to 180 candelas per square centimeter, and likewise the color temperature from 3600 to 3800°K, exceeding those from incandescent tungsten. See Figure 39 for spectral outputs.

The high intensity arcs range in input power from 2 to 30 kilowatts, in crater luminous intensity from 10,500 to 185,000 candelas, and in crater luminance from 55,000 to 145,000 candelas per square centimeter. The color temperature varies from 2900°K to as high as 6500°K, corresponding to the sun's color temperature. These values are modified by the characteristics of the optical system used with them. One notable example of a carbon arc searchlight emits an intensity of 68,000 candelas, a crater luminance of 65,000 candelas per square centimeter, and has a color temperature of 5400°K. See Table 16 for various direct current carbon arc applications.

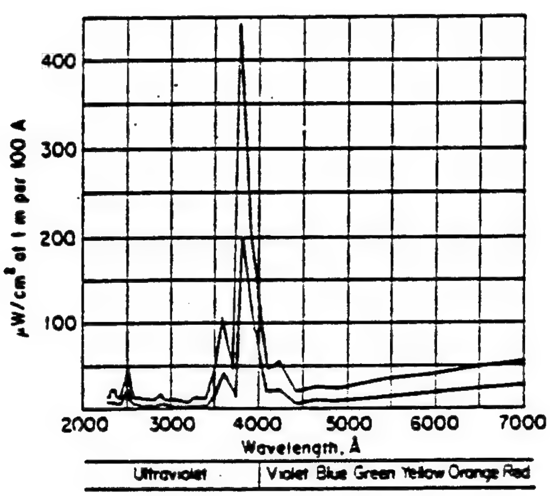
Figure 40 shows the spectral power distribution of flame arcs used for graphic arts. Table 17 shows the wide variety of effects achieved with the use of flame additives. Table 18 provides additional arc data. Flame arcs have power inputs ranging from 1 to 4 kilowatts, and show the effect of different currents, voltages



(a) Spectral Distribution of Radiant Flux from 30-A, 55-V dc Low Intensity Arc with 12-mm Positive Carbon (Solid Line) and of a 3800° K Blackbody Radiator (Broken Line).



(b) Spectral Energy Distribution of Carbon Arc with Core of Soft Carbon: Upper Curve; 60-A ac, 50-V Across the Arc; Lower Curve: 30-A ac, 50-V Across the Arc.



(c) Spectral Energy Distribution of Carbon Arc with Polymetallic-Cored Carbons: Upper Curve: 60-A ac, 50-V Across Arc; Lower Curve: 30-A ac, 50-V Across Arc.

Figure 39. Examples of Spectral Energy Distribution of Various Carbon Arcs

Table 16

Direct-Current Carbon Arc

	Low Intensity	Non-Rotating High Intensity		Rotating High Intensity				
	Application Number*							
	1	2	3	4	5	6	7	8
Type of Carbon	Microscope	Projector	Projector	Projector	Projector	Projector ***	Searchlight	Studio "Yellow Flame"
Positive Carbon								
Diameter, mm (in.)	5	7	8	10	11	13.6	16	16
Length, mm (in.)	200(8)	300-355(12-14)	300-355(12-14)	500(20)	500(20)	318(12.5)	560(22)	560(22)
Negative Carbon								
Diameter, mm (in.)	6	6	7	9(11/32)	10(3/8)	13(1/2)	11	13.5(17/32)
Length, mm (in.)	114(4 1/2)	230(9)	230(9)	230(9)	230(9)	230(9)	300(12)	230(9)
Arc current, amps	5	50	70	105	120	160	150	225
Arc volts, dc	59	40	42	59	57	66	78	70
Arc power, watts	295	2000	2940	6200	6840	10600	11700	15800
Burning rate, mm (in.) per hour								
Positive carbon	114(4.5)	295(11.6)	345(13.6)	546(21.5)	419(16.5)	432(17.0)	226(8.9)	513(20.2)
Negative carbon	53(2.1)	109(4.3)	109(4.3)	74(2.9)	61(2.4)	56(2.2)	99(3.9)	56(2.2)
Approximate crater diameter, mm (in.)	3(0.12)	6(0.23)	7(0.28)	9(.36)	10(0.39)	13(0.50)	14(0.55)	15(0.59)
Max. luminance of crater, candelas	15000	55000	83000	90000	85000	96000	65000	68000
Forward Crater candlepower,	975	10500	22000	36000	44000	63000	68000	99000
Crater lumens**	3100	36800	77000	126000	154000	221000	250000	347000
Total lumens†	3100	55000	115000	189000	231000	368000	374000	521000
Total lumens per Arc	10.4	29.7	39.1	30.5	33.8	34.7	32.0	33.0
Color temp. kelvins‡	3600	5950	5500-6500	5500-	5500-	5500-	5400	4100

*Typical applications: 1, microscope illumination and projection; 2,3,4,5, and 6, motion picture projection; 7, search projection; 8, motion picture set lighting motion picture and television background projection.

**Includes light radiated in forward hemisphere.

†Includes light from crater and arc flame in forward hemisphere.

‡Crater radiation only.

***Jointed carbon.

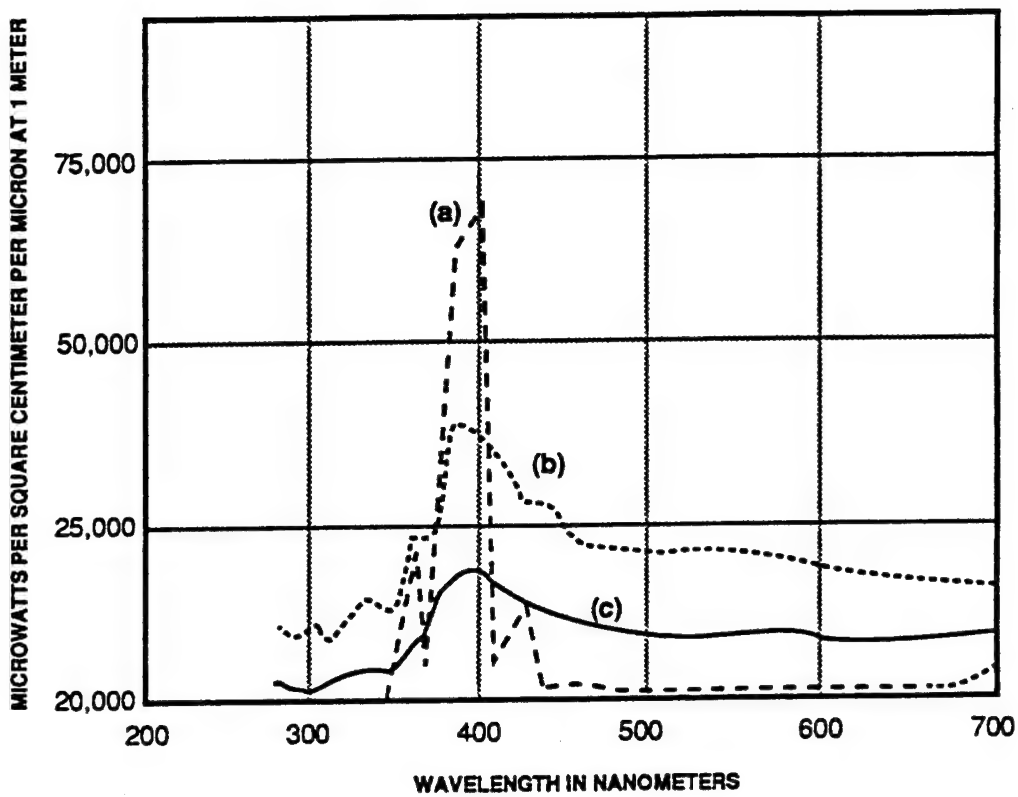


Figure 40. Spectral Power Distribution of Arcs Used for Graphic Arts. (a) Half-inch Enclosed Arc Carbons, 16 Amperes, 138 Volts. (b) Nine Millimeter High Density Photo Carbons, 95 Amperes, 30 Volts. (c) Half-inch Photographic White Flame Carbons, 38 Amperes, 50 Volts.

Table 17

Flame-Type Carbon Arcs

	Application Number[a]				
	1	2	3	4	5[c,a]
Type of Carbons	"Sunshine"	"Sunshine"	Enclosed arc	Photo[b]	Photo[c]
Flame Materials	Rare earth	Rare earth	None	Rare earth	Rare earth
Burning Position[d]	Vertical	Vertical	Vertical	Vertical	Horizontal
Upper carbon[e]					
Diameter, millimeters (inches)	22(7/8)	22(7/8)	13(1/2)	13(1/2)	9(3/8)
Length, millimeters (inches)	300(12)	300(12)	75 to 400 (3 to 16)	300(12)	200(8)
Lower carbon[e]					
Diameter, millimeters (inches)	13(1/2)	13(1/2)	13(1/2)	13(1/2)	9(3/8)
Length, millimeters (inches)	300(12)	300(12)	75 to 400 (3 to 16)	300(12)	200(8)
Arc current, amperes	60	80	16	38	95
Arc voltage, ac[f]	50	50	138	50	30
Arc power, kilowatts	3.0	4.0	2.2	1.9	2.85
Candlepower[g] (candelas)	9100	10000	1170	6700	14200
Lumens	100000	110000	13000	74000	156000
Lumens per arc watt	33.33	27.5	5.9	39.8	54.8
Color temperature, kelvins	12800[h]	24000[h]	[h]	7420[h]	8150
Spectral intensity (microwatts per square centimeter one meter from arc axis[i])					
Below 270 nm	102	140	--	95	--
270-320 nm	186	244	--	76	100
320-400 nm	2046	2816	1700	684	1590
400-450 nm	1704	2306	177	722	844
450-700 nm	3210	3520	442	2223	3671
700-1125 nm	3032	3500	1681	1264	5632
Above 1125 nm	9820	11420	6600	5189	8763
Total	20100	24000	10600	10253	20600
Spectral radiation (per cent of input power)					
Below 270 nm	.34	.35	--	.5	--
270-320 nm	.62	.61	--	.4	.35
320-400 nm	6.82	7.04	7.7	3.6	5.59
400-450 nm	5.68	5.90	.8	3.8	2.96
450-700 nm	10.70	8.80	2.0	11.7	12.86
700-1125 nm	10.10	8.75	7.6	6.7	19.75
Above 1125 nm	32.70	28.55	29.9	27.3	30.69
Total	67.00	60.00	48.0	54.0	72.20

[a]Typical applications: 1 and 2, accelerated exposure testing, or accelerated plant growth; 3, 4, and 5 blueprinting, diazo printing, photo copying, and graphic arts.

[b]Photographic white flame carbons.

[c]High intensity photo 98 carbons.

[d]All combinations shown are operated coaxially.

[e]Both carbons are same in horizontal, coaxial ac arcs.

[f]All operated on alternating current.

[g]Horizontal candlepower, transverse to arc axis.

[h]Deviate enough from blackbody colors to make color temperature of doubtful meaning.

[i]See 1981 Application Volume, Section 11 Fig. 11-18 for spectral power distribution curve.

Table 18
Additional Arc Data

Electric Arcs

(1) Enclosed Concentrated - Arc Lamps:

Watts	Average Luminance (cd/cm^2)	Average Intensity cd	Max. Temp. °C
2	2400	0.3	60
10	4500	4.7	107
25	3500	16.0	179
100	3800	100	243
300	4500	275	271

(2) Direct Current Carbon Arc:

Use	Microscope	Projectors					Search	Movie
Watts	295	2000	2940	6200	6840	10600	11700	15800
Tot. Lumens	3100	55000	115000	189000	231000	368000	374000	521000
Max. Luminance of crater (cd/cm^2)	15000	55000	83000	90000	85000	96000	65000	68000
Forward Crater Intensity (cd)	975	10500	22000	36000	44000	63000	68000	99000
Crater Lumens	3100	36800	77000	12600	154000	221000	250000	347000
Color Temp.	3600	5950	6500	6500	6500	6500	5400	4100

and flame materials. The wavelength intervals are chosen to coincide with the needs of various applications.

H. Spontaneous Spark, Flash, Steady Burning Sources

1. Electrical spark
2. Gun flashes (security personnel weapons):
   - M-16 rifles
   - M-60 machine guns
   - M-79 grenade launchers
   - 38 caliber pistols
   - 12 gauge shotguns
3. Aircraft engine:
   - wet start
   - backfire
   - 20-80% power levels
   - black powder cartridge start

1. Sparks and Gun Flashes

As described previously, it may take only some small increment of radiation from some seemingly minuscule source somewhere to push the fire detectors over the already nearly

satisfied threshold into a false alarm. A single spark or the firing of any weapon can be such a source. Since the gunpowder on explosion gives a very high peak intensity, very short duration pulse of radiation in the UV, visible and IR bands of radiation, it appears that the best characteristic to use to achieve immunity to such events is to exploit pulse width discrimination against them. Besides proper knowledge of the spectral energy distribution of such a pulse being desirable, the more practical characteristic to use is the pulse duration of each firing cubicle. This can be applied more simply in fire detector circuitry. Hence, this needs to be determined for all the candidate security personnel weapons, namely:

M-16 rifle
M-60 machine gun
M-79 grenade launcher
38 caliber pistol
12 gauge shotgun

The flash pulse characteristics can be readily determined with a fast responding photodetector and scope. This needs to be done in laboratory/field measurements under both daytime and nighttime conditions.

2. <u>Aircraft Engine Emissions</u>

Results of tests by other investigators indicate that both UV and IR emissions occur during engine start-up, and reheat in a hangar. Indication is that the UV and IR fire detectors do not trigger during normal start-up, but will trigger during reheat.

One source reports that during start-up through reheat:

<u>Infrared Measurement:</u> at 4.38 μm center wavelength, with a bandwidth of 0.7 μm, and at a distance of 10 meters (3.28 feet):

(1) peak irradiance = 500 $\mu W/cm^2$
(2) average irradiance = 100 $\mu W/cm^2$.

This is similar to a 1 square foot JP-4 fuel panfire at 15 meters (49.2 feet):

(1) irradiance $\cong$ 100 $\mu W/cm^2$;

and to a 4 square foot JP-4 fuel panfire likewise at 15 meters:

(2) irradiance $\cong$ 500 $\mu W/cm^2$.

<u>Ultraviolet Measurements:</u> an avalanche counter detector in the 190 to 260 nm UV band, at a distance of 10 meters (32.8 feet) indicated:

(1) engine start up: no counts
(2) engine idle: no counts
(3) engine at 80% power: no counts
(4) engine during reheat: very high counts

This response is similar to that of a 2 square foot JP-4 fuel panfire at 6 meters (19.7 feet).

At these levels of UV and IR output during reheat, but not during the other periods of engine operation, the various combinations of UV and IR fire detectors would false alarm.

I. Reflected and Scattered Light

Besides the direct light from any false alarm source, the possibility of its reflected light adding to its direct light to trigger a fire detector system is considerable. As is seen in Table 19, the reflectance of UV in the region of mercury's strong wavelength at 253.7 nm is relatively high from a variety of surfaces.

Table 19

Reflectance of Various Materials for Energy Wavelengths in the Region of 253.7 nm

Material	Reflectance (percent)
Aluminum	
Untreated surface	40-60
Treated surface	60-89
Sputtered on glass	75-85
Paints	55-75
Stainless steel	25-30
Tin plate	25-30
Magnesium oxide	75-88
Calcium carbonate	70-80
New plaster	55-60
White baked enamels	5-10
White oil paints	5-10
White water paints	10-35
Zinc oxide paints	4-5

Hangars typically have extensive metallic surfaces, both coated and uncoated, as well as all kinds of other surfaces, both permanent and temporary, which are all either specular, spread, diffuse, or compound reflectors of light. They also can be either spectrally selective or non-selective in their reflectance. Figure 41 shows the reflectance characteristics of materials of interest, particularly in the ultraviolet region. Table 20 shows the reflectance and transmittance characteristics of some materials of

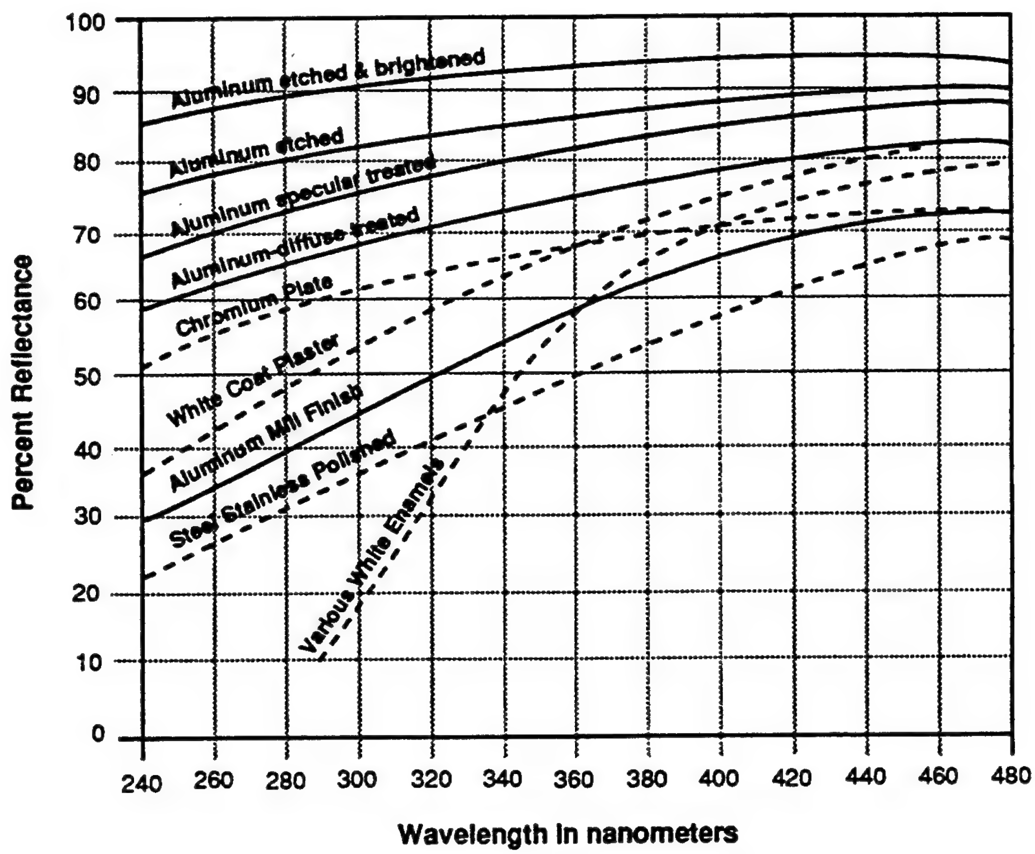


Figure 41. Spectral Reflectance Characteristics of Various Materials in the Blue, Violet, and UV Spectral Regions.

Table 20

Reflectance (R) and Transmittance (T) Properties of Materials Used for Lighting In the Visible and Infrared Regions

Material	Visible Wavelengths						Near Infrared Wavelengths						Far Infrared Wavelengths							
	400 nm		500 nm		600 nm		1000 nm		2000 nm		4000 nm		7000 nm		10,000 nm		12,000 nm		15,000 nm	
	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T	R	T
Specular aluminum	87	0	82	0	86	0	97	0	94	0	88	0	84	0	27	0	16	0	14	0
Diffuse Aluminum	79	0	75	0	84	0	86	0	95	0	88	0	81	0	68	0	49	0	44	0
White synthetic enamel	48	0	85	0	84	0	90	0	45	0	8	0	4	0	4	0	2	0	9	0
White porcelain enamel	56	0	84	0	83	0	76	0	38	0	4	0	2	0	22	0	8	0	9	0
Clear glass-3.2 millimeters (.125 inch)	8	91	8	92	7	92	5	92	23	90	2	0	0	0	24	0	6	0	5	0
Opal glass-3.9 millimeters (.155 inch)	28	36	26	39	24	42	12	59	16	71	2	0	0	0	24	0	6	0	5	0
Clear acrylic-3.1 millimeters (.120 inch)	7	92	7	92	7	92	4	90	8	53	3	0	2	0	2	0	3	0	3	0
Clear polystyrene-3.1 millimeters (1.20 inch)	9	87	9	89	8	90	6	90	11	61	4	0	4	0	4	0	4	0	5	0
White acrylic-3.2 millimeters (.125 inch)	18	15	34	32	30	34	13	59	6	40	2	0	3	0	3	0	3	0	3	0
White polystyrene-3.1 millimeters (.120 inch)	26	18	32	29	30	30	22	48	9	35	3	0	3	0	3	0	3	0	4	0
White vinyl-0.75 millimeters (.030 inch)	8	72	8	78	8	76	6	85	17	75	3	0	2	0	3	0	3	0	3	0

Note: (a) Measurements in visible range made with General Electric Recording Spectrophotometer. Reflectance with black velvet backing for samples. (b) Measurements at 1000 nm and 2000 nm made with Beckman DK2-R Spectrophotometer. (c) Measurements at the wavelengths greater than 2000 nm made with Perkin-Elmer Spectrophotometer. (d) Reflectances in infrared relative to evaporative aluminum on glass.

Table 21 shows the reflectances of a wide variety of materials.

Table 21

Material	Reflectance* or Transmittance† (per cent)	Characteristics
		Reflecting
Specular		
Mirrored and optical coated glass	80 to 99	Provide directional control of light and brightness at specific viewing angles. Effective as efficient reflectors and for special decorative lighting effects.
Metalized and optical coated plastic	75 to 97	
Processed anodized and optical coated aluminum	75 to 95	
Polished aluminum	60 to 70	
Chromium	60 to 65	
Stainless steel	55 to 65	
Black structural glass	5	
Spread		
Processed aluminum (diffuse)	70 to 80	General diffuse reflection with a high specular surface reflection of from 5 to 10 per cent of the light.
Etched aluminum	70 to 85	
Satin chromium	50 to 55	
Brushed aluminum	55 to 58	
Aluminum paint	60 to 70	
Diffuse		
White plaster	90 to 92	Diffuse reflection results in uniform surface brightness at all viewing angles. Materials of this type are good reflecting backgrounds for coves and luminous forms.
White paint**	75 to 90	
Porcelain enamel**	65 to 90	
White terra-cotta**	65 to 80	
White structural glass	75 to 80	
Limestone	35 to 65	
		Transmitting
Glass††		
Clear and optical coated	80 to 99	Low absorption; no diffusion; high concentrated transmission. Used as protective cover plates for concealed light sources
Configurated, obscure, etched, ground, sandblasted, and frosted	70 to 85	Low absorption; high transmission; poor diffusion. Used only when backed by good diffusing glass or when light sources are placed at edges of panel to light the background.
Opalescent and alabaster	55 to 80	Lower transmission than above glasses; fair diffusion. Used for favorable appearance when indirectly lighted.
Flashed (cased) opal	30 to 65	Low absorption; excellent diffusion. Used for panels of uniform brightness with good efficiency.
Solid opal glass	15 to 40	Higher absorption than flashed opal glass; excellent diffusion. Used in place of flashed opal where a white appearance is required.
Plastics		
Clear prismatic lens	70 to 92	Low absorption; no diffusion; high concentrated transmission. Used as shielding for fluorescent luminaires, outdoor signs and luminaires.
White	30 to 70	High absorption; excellent diffusion. Used to diffuse lamp images and provide appearance in fluorescent luminaires.
Colors	0 to 90	Available in any color for special color rendering lighting requirements or esthetic reasons.
Marble (impregnated)	5 to 30	High absorption; excellent diffusion; used for panels of low brightness. Seldom used in producing general illumination because of the low efficiency.
Alabaster	20 to 50	High absorption; good diffusion. Used for favorable appearance when directly lighted.

*Specular and diffuse reflectance.

**These provide compound diffuse-specular reflection unless matte finished.

† The figures given are based on thicknesses generally used in lighting applications and on near normal angles of incidence.

interest, particularly in the infrared region.

J. Other Radiations

1. HF radios, tail and wings:
2. attack radar:
   normal beam
   pencil beam
3. attack radar (5 sec icc.)
4. TF/BU through attack, ECM (IR jamming)
5. APU/60

For these electromagnetic radiation sources see Military Standard 461 and 462.

1. Electromagnetic Waves

The sources of radiation that can cause false alarms can emanate from:

(1) communication systems
(2) attack radars
(3) terrain-following radars
(4) weapons systems
(5) electronic countermeasure jammers
(6) other aircraft and hangar equipment generating electromagnetic emissions

Although not the same as x-rays for penetrating through shielding materials, the capability to induce effects in the electronics of fire detection systems can trigger a false alarm. Such induced effects may enter well-shielded circuitry through some component in a position to effectively function as an antenna into an enclosure, or enter by way of the power line. Until it happens, it is difficult to predict such an effect, or even protect against it fully. It is one effect to consider when all other possible effects have been ruled out as the cause of a false alarm. (See Military Standards 461 and 462).

2. Non-Destructive Investigative Devices

The principal instrument used for non-destructive investigative purposes is the X-ray machine. Since its electrical operation requires very high voltages and currents to produce the particular x-ray energies required, whether in a pulsed or steady mode, the concomitant requirements for shielding against stray and/or reflected radiation, as well as proper shielding and grounding of all electrical parts of the system, are of utmost importance. Besides the capability to produce secondary radiation in the ultraviolet region, along with the x-ray radiation itself, which can penetrate and ionize gas-filled UV fire detectors, it is also possible to generate EMI/RFI radiation which can affect the

circuitry of the detector system either through the power cables or by pickup in some other way.

Such machines generate hard x-ray energies from 160 to 300 Kev, with wavelengths from 0.385 to 0.205 Angstroms. Their capability to reflect from and penetrate metals over the thickness ranges and materials of interest provide an investigative tool sometimes necessary to use on an aircraft in a hangar. This demands that proper precautions be taken to avoid triggering a false alarm.

K. Nuclear Sources	Approx. Average Luminance cd/m^2	Spectra Band
1. atomic fission bomb: 0.1 msec after firing, 30 m diameter ball:	2×10^{12}	X-UV-VIS-IR
2. atomic fusion bomb:	2×10^{10}	X-UV-VIS-IR
3. radioluminescent signs and markers:	3×10^{-1}	Phosphor dependent (usually green)

L. Summary of All Lamps

Table 22 gives a summary of important lamps of all categories regarding wattage, approximate initial lumens and approximate initial efficacy in lumens per lamp watt.

The terms "color temperature" and "color rendering index" need clarification, since they can be easily misunderstood and be misleading.

Color temperature is a parameter frequently given for any kind of light source where the color of the light comes close to that of a blackbody at the designated temperature, and which would be defined for its color characteristics on a chromaticity diagram accordingly. It is not the absolute temperature of the filament, but is related to it to the extent that, as the filament temperature goes up, so does the color temperature go up.

The "color rendering index" refers to the fact that each kind of lamp illuminates different colored objects differently. Two "white light" lamps, because of the spectral content of their emitted light, can result in shades or tones, or even colors of reflected light from colored objects being visually different. For instance, lighting a red object with a mercury arc lamp will cause the object to appear black or gray. Hence, to aid lighting engineers to choose proper lamps for illuminating garments, for

instance, in a clothing store, the CRI of a lamp aids in making a proper choice. The higher the CRI, the nearer the lamp is to true "white light".

These two parameters, color temperature and color rendering index, are of no consequence in hangar lighting.

Table 22

Filament Temperatures and Efficacies of 120 Volt Incandescent Lamps

Lamp Watts	Bulb Size	Approx. Filament Temp. °F.	Approx. Filament Temp. °K.	Approx. Color Temp. Kelvin	Approx. Initial Lumens	Efficacy Lumens per Watt
6*	S-14	3860	2399	2370	40	6.5
10*	S-14	3900	2422	2450	86	8.0
25*	A-17	4190	2583	2550	235	9.4
40	A-17	4470	2739	2770	460	11.5
60	A-17	4530	2772	2800	890	14.8
100	A-17	4670	2850	2870	1750	17.4
150	A-21	4710	2872	2900	2850	19.2
200	A-23	4760	2899	2930	3940	19.7
300	PS-30	4830	2939	2940	6000	20.0
500	PS-35	4840	2944	2960	10600	21.0
1000	PS-52	4980	3022	3030	23100	23.1
1500	PS-52	5010	3039	3070	33620	22.4

*Vacuum

Not only is the color temperature higher for lamps of greater efficacy, but for any particular lamp the color temperature increases with line voltage.

Table 23 provides further information covering all the major categories of light sources.

Table 23

Efficacies of Illuminants

The theoretical maximum efficacy of 680 LM/W is that which would be obtained if all the power input were emitted as green light at a wavelength of 555 nm (at which the eye is most sensitive). If all power could be emitted uniformly over the visible spectrum as white light, the efficacy would be of the order of 220 lm/W.

Fluorescent life-ratings are based upon 3 hrs of operation per

start. Life increases as lamps are burned for longer periods.

Lamp	Lamp watts	Rated average life, hours	Approx. initial lumens	Approx. initial efficacy, lm/lamp W
A. Tungsten filament (120 V)				
Vacuum	25	2,500	235	9.4
Gas filled	40	1,500	455	11.4
Gas filled	60	1,000	870	14.5
Gas filled	75	750	1,190	15.9
Gas filled	100	750	1,750	17.5
Gas filled	200	750	4,010	20.1
Gas filled	500	1,000	10,850	21.7
Gas filled	1,000	1,000	23,740	23.7
Gas filled (3,200 K)	5,000	150	145,000	29.0
Gas filled (3,200 K)	10,000	75	335,000	33.5
B. Fluorescent (cool white)				
Preheat (T12)	20	9,000	1,300	65.0
Rapid start (T12)	40	20,000	3,150	78.8
Rapid start (T12, shielded cathode)	40	15,000	3,250	81.3
Rapid start (T12, U shaped, 3 5/8-in. leg)	40	12,000	2,900	72.5
Slimline (96T12 425 Ma)	75	12,000	6,300	84.0
Preheat (T17)	90	9,000	6,400	71.1
High output (96T12, 800 Ma)	110	12,000	9,200	83.6
Grooved lamp (96PG17, 1500 Ma)	215	9,000	16,000	74.4
C. Fluorescent (other)				
Rapid start (T12, deluxe cool white)	40	20,000+	2,200	55.0
Rapid start (T12, white)	40	20,000+	3,200	80.0
Rapid start (T12, warm white)	40	20,000+	3,150	78.7
Rapid start (T12, deluxe warm white)	40	20,000+	2,150	53.7
Rapid start (T12, daylight)	40	20,000+	2,600	65.0
Rapid start (T12, natural)	40	20,000+	2,100	52.5
Rapid start (T12, 5,000 K)	40	20,000+	2,200	55.0
Rapid start (T12, 7,500 K)	40	20,000+	2,000	50.0
Rapid start (T12, blue)	40	20,000+	1,160	29.0
Rapid start (T12, gold)	40	20,000+	2,400	60.0
Rapid start (T12, green)	40	20,000+	4,500	112.5
Rapid start (T12, pink)	40	20,000+	1,160	29.0
Rapid start (T12, red)	40	20,000+	200	5.0
D. High-intensity discharge (HID)				
1. Mercury vapor (E-37)				
Clear	400	24,000	21,000	52.5
Color improved	400	24,000	20,500	51.3

Lamp	Lamp watts	Rated average life, hours	Approx. initial lumens	Approx. initial efficacy, lm/lamp W
Deluxe white	400	24,000	22,500	56.3
Warm deluxe white	400	24,000	20,000	50.0
2. Mercury vapor (BT-56)				
Clear	1,000	24,000	57,000	57.4
Color improved	1,000	24,000	55,000	55.0
Deluxe white	1,000	24,000	63,000	63.0
Warm deluxe white	1,000	24,000	58,000	58.0
3. Metal halide				
E-37	400	10,000	34,000	85.0
BT-56	1.000	10,000	100,000	100.0
BT-56	1.500	1,500	155,000	103.3
4. High pressure sodium (Lucalox)				
	100	12,000	9,500	95.0
	150	12,000	16,000	106.7
	250	15,000	30,000	120.0
	400	20,000	50,000	125.0
	1,000	15,000	140,000	140.0
E. Electric arc				
High intensity	11,700	—	36,800	31.4

Bibliography

1. Coon, J. Walter, "Fire Protection, Design, Criteria, Options, Selection," R.S. Means Co., Inc., Kingston, MA, 1991.

2. Driscoll, Walter G, Editor, and William Vaughan, Associate Editor, "Handbook of Optics," McGraw-Hill Inc., New York, 1978.

3. "Gilway Technical Lamp: Engineering Catalog 162," Gilway Technical Lamp Co., Woburn, MA.

4. Green, A. E. S., Editor, "The Middle Ultraviolet: Its Science and Technology," John Wiley & Sons, Inc., New York, 1966: Chapter 8: The Middle Ultraviolet and Air Pollution.

5. "Guide to Incandescent Lamps," North American Philips Lighting Corp., Bloomfield, NJ, 1986.

6. "Guide to High Intensity Discharge Lamps," North American Philips Lighting corp., Bloomfield, NJ, 1983.

7. "Guide to High Intensity Discharge Lamps," Philips Lighting Co., Somerset, NJ, 1988.

8. "Hanovia Compact Arc Lamps," Hanovia Co., Newark, NJ, 1986.

9. Kaufman, John E., Editor, and Jack F. Christensen, Associate Editor, "IES Lighting Handbook," Reference Volume, IES of North America, New York, 1984.

10. Kaufman, John E., Editor, and Jack F. Christensen, Associate Editor, "IES Lighting Handbook," Application Volume, IES of North America, New York, 1987.

11. Lerner, Rita G. and George L. Trigg, Editors, "Encyclopedia of Physics," Second Edition, VCH Publishers, Inc., New York, 1991.

12. "Lamp Specification Guide, SG-100," Philips Lighting Co., Somerset, NH, 1988.

13. "Lamps Specification and Application Guide," Philips Lighting Co., Somerset, NJ, 1991.

14. "Light Sources, Monochrometors, Detection Systems," Volume II, Oriel Corp., Stratford, CT, 1989.

15. Linford, H.M.F. and C.F. Dillon, "Optical Emission Properties of Aircraft Combustible Fluids," Technical Report AFAPL-TR-73-83, Mcdonnell Aircraft Co., St. Louis, MO, August 1973.

16. Lindsey, Jack L., "Applied Illumination Engineering," Fairmont Press, Lilburn, GA, 1991.

17. "Miniature/Sealed Beam Lamp Catalog," GE Lighting, Nela Park, Cleveland, 1991.

18. "Miniature, Subminiature, Sealed Beam and Halogen Cycle Lamp Catalog," 520 Weatherly Index, Nela Park, Cleveland.

19. "Optical Radiation Emissions from Selected Sources. Part I. Quartz Halogen and Fluorescent Lamps," Environmental Research Labs., Scottsdale, AZ, PBSI-139693, October 1980.

20. "Optical Radiation Emissions from Selected Sources. Part 2. High Intensity Discharge Lamps," U.S. Food and Drug Administration, Rockville, MD, PB85-149136, November 1984.

21. Roberts, J.K., "Heat and Thermodynamics," Third Edition, Blackie & Son Ltd. London, 1942.

22. "Selection Guide for Quality Lighting, Forum 9200 20th Edition, GE Lighting Institute at Nela Park, Cleveland, 1991.

23. "Sylvania Miniature and Sealed Beam Lamp Catalog," Catalog 205, GTE Products Corp., Hillsboro, NH, 1984.

24. "Sylvania Incandescent Lamps," Engineering Bulletin 0-324, GTE Products Corp., Lighting Center, Donvers, MA.

25. "Sylvania High Intensity Discharge Lamps," Engineering Bulletin 0-344, Metalarc Lamps, GTE Products Corp., Lighting Center, Donvers, MA.

26. "Sylvania High Intensity Discharge Lamps," Engineering Bulletin 0-346, Mercury Lamps, GTE Products Corp., Lighting Center, Donvers, MA.

27. "Sylvania High Pressure Sodium," Engineering Bulletin 0-348, Lumalux and Unalux Lamps, GTE Products Corp., Lighting Center, Donvers, MA.

28. "Sylvania Fluorescent Lamps," Engineering Bulletin 0-341, GTE Products Corp., Lighting Center, Donvers, MA.

29. "Sylvania Tungsten Halogen Lamps, " Engineering Bulletin 0-349, GTE Products Corp.,Lighting Center, Donvers, MA.

30. "Short Arc Lamps," Optical Radiation Corp., Lamp Division, Azusa, CA 1986.